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IRRADIATION OF A TELEMETERING SYSTEM AND RELATED RECONNAISSANCE SENSORS

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(Prepared under Contract Nr AF 33(657)-7229 by Chance Vought Corporation, Dallas, Texas; B. T. Lowrey and J. C. Mitchell, authors,)

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FOREWORD

This report was prepared by Chance Vought Corporation under USAF Contract No. AF 33(657)-7229. This contract was initiated under Project No. 655A, and the work was administered under the direction of the Nuclear Systems Section of the Directorate of Advanced Systems Planning, Deputy Commander/Technology, Aeronautical Systems Division, with Mr. Louis J. Urban as task manager.

This report covers work conducted from August 30, 1961 to April 1, 1962.

Successful completion of this work was made possible by the cooperation of the Advanced Guidance, Avionics and Instrumentation, and Astrionics Groups at Chance Vought. Particular appreciation is extended to Messrs. C. C. Ogden, F. M. Ekert, R. W. Hill, and C. L. Buddecke. The cooperation of personnel at the Nuclear Aerospace Research Facility during the irradiation test is also acknowledged.

ABSTRACT

Research was performed in

~~This report documents the work performed~~ ~~in~~ modifying, instrumenting, and irradiating a mini~~mum~~ telemetering system, and in evaluating the possible use of xerographic storage plates and photomultipliers in a nuclear radiation environment. A partially hardened 230 Mc telemetering subsystem consisting of ~~ten~~ 18 sensors, two SCO's, mixer amplifier, FM/FM transmitter, and PM/FM transmitter was dynamically irradiated at the 3 Mw Ground Test Reactor (GTR) for 100 continuous ~~hours~~ hr during September, 1961. The average integrated nuclear radiation exposure for the subsystem was 3.0×10^{16} n_f/cm^2 (nE > 1.0 Mev) and 8.0×10^{10} ergs/gm-(C). Failure of the low pass filters in the two SCO's occurred after an exposure of 4.0×10^{14} n_f/cm^2 (nE > 1.0 Mev), 1.3×10^{9} ergs/gm-(C). Transmitter output power ~~of~~ the FM/FM and PM/FM transmitters failed after an exposure of 6.0×10^{15} n_f/cm^2 (nE > 1.0 Mev), 2.0×10^{10} egs/gm(C) and 3.0×10^{14} n_f/cm^2 (nE > 1.0 Mev), 8.0×10^{8} ergs/gm-(C), respectively.

There was no gross change in dark resistivity of a photosensitive amorphus selenium (xerographic) detector after exposure in the GTR's 2 7/8 in~~ch~~ square pneumatic tube ~~to 1.1 x 10^8 nf/cm2-sec (nE > 1.0 Mev) 2.1 x 10^7 ergs/gm-hr(C)~~ for ~~ten~~ 10 minutes.

Four

~~Two~~ RCA No. 5819, 10 stage, S11 spectrum and two DuMont No. 6292, 10 stage, ~~S11~~ spectrum photomultiplier tubes were dynamically irradiated in ~~General Dynamics~~' 3000 curie Co^{60} gamma source ~~on October 1, 1961~~, to investigate the degree of gamma photon induced dark current saturation. Both types of phototubes exhibited stable response to high light stimuli in a nuclear environment of 2.0×10^{7} ergs/gm-hr(C).

Publication Review

This technical documentary report has been reviewed and is approved.

Fred B. Orazio

for JOHN R. HOOD, JR.
Colonel, USAF
Director, Advanced Systems Planning
Deputy Commander/Technology

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This report documents the work performed in modifying, instrumenting, and irradiating a minimum telemetering system, and in evaluating the possible use of xerographic storage plates and photomultipliers in a nuclear radiation environment. The telemetry work has direct application to the development of a telemetering system for the nuclear ramjet vehicle.

The nuclear ramjet missile flight test configured vehicles will include radio command control capabilities. In order to realize a complete closed loop system, selected missile parameters relating aerodynamic, propulsion, and electronic system performance to command functions must be visually displayed in real time at the command consoles. The measurement, transduction, signal conditioning, and transmission of the various quantities will be accomplished by an appropriate multi-channel telemetering subsystem, and additional telemetry will provide the means for acquisition of vehicle flight test performance data for analytical purposes. Thus, the importance of an accelerated telemetry subsystem development must be emphasized and immediate attention given to preliminary testing of telemetry processes and techniques in a nuclear radiation environment.

As a first step in this development, a minimum telemetering system was prepared from selected components and tested in the radiation environment of the Air Force Ground Test Reactor (GTR) at the Nuclear Aerospace Research Facility (NARF). The system consisted of a V.H.F. low-power frequency modulated telemetering transmitter, a V.H.F. low-power phase modulated telemetering transmitter, a linear mixer amplifier, two IRIG (Inter-Range Instrumentation Group) subcarrier oscillators and ten representative transducers. Specific details of each component are given in the text of the report.

Nuclear ramjet missiles may be used for a number of missions, one or more of which may require some reconnaissance capability. Because of the nuclear radiation susceptibility of most reconnaissance sensors, very few of the reconnaissance concepts have been evaluated. One possible method which utilizes an electrostatic process was investigated to evaluate its usefulness in a nuclear radiation environment. A special test fixture was built to measure charge leakage from an experimental xerographic plate, when exposed to radiation in the GTR rabbit tube. Details are discussed in the body of this report.

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Two types of photomultiplier tubes were investigated to determine their sensitivity to light radiation while in a gamma photon field of about 10^5 r/hr. This was accomplished by placing the photomultipliers in the NARF's gamma irradiator along with a light source. Dynamic operation of the phototubes revealed that they could sense a light pulse even in the presence of a "saturated" dark current condition produced by nuclear radiation.

In addition to the test articles contractually committed to testing, irradiation space was made available for two additional test articles: (1) a servo actuator package, and (2) a permanent magnet generator. These items were modified and instrumented for testing under a joint industry and Chance Vought program. A separate and complete report is being prepared on these items and will be furnished to the Air Force as soon as it is completed.

The following sections of the document describe in detail the work performed on Air Force Contract AF33(657)-7229.

II. NUCLEAR IRRADIATION EVALUATION OF THE TELEMETERING SYSTEM

2.1 Introduction

Nuclear radiation emitted from the nuclear ramjet missile reactor is an added environmental parameter that causes the characteristic performance of an electronic system to change as a result of neutron, gamma photon, and secondary radiation interaction with the materials of the system. No theory now exists which will mathematically correlate the amount of nuclear radiation exposure with the resultant property changes of a material; consequently, the study of radiation damage is directly linked to experimental data. The predictions and design studies which can be made, at present, are no more accurate than the methods by which test data are analyzed and used.

The reliability of an electronic system in a nuclear radiation environment is dependent upon the reliability of its individual active and passive components which in turn are dependent upon the reliability of their specific materials. System reliability in a nuclear environment can be correlated to the weakest component in the system, i.e., the component having the greatest adverse property changes due to material degeneration. Therefore, the nuclear radiation tolerance level can be increased by replacing the weakest components and materials with more radiation tolerant substitutes, or in some cases by redesigning circuits to eliminate low tolerance active or passive components where suitable substitutes are not available.

The objective of the Telemetering Radiation Effects Evaluation Study was to investigate telemetry processes and techniques in a nuclear radiation environment, and to establish the functional damage threshold of a typical telemetering system in a nuclear radiation environment.

The telemetering system is defined here as that portion of a data system involved with the acquisition, conversion, and transmission of typical flight test performance intelligence. The irradiated telemetering system components were combined in a telemetry configuration as shown in Figures 1 and 2, employing both FM/FM and PM/FM techniques and consisting of:

a. Input D. C. Signals (data to be transmitted)

1. 0, 2.5, 5 volt step inputs
2. Six pressure transducers (0 to 5 volts output)
3. Two double angular position transducers (0 to 5 volts output)

b. Voltage Controlled Subcarrier Oscillators

1. 10.5 kc Vector Model S-81b

2. 14.5 kc Vector Model S-81b

c. Mixer-Amplifier, Vector Model A-80

d. 230 Mc Crystal Controlled Telemetering Transmitters

1. 2 watt FM/FM Telechrome Model 1472A2

2. 2 watt PM/FM Bendix Model TXV-13

A schematic block diagram of the system is presented in Figure 1 with dashed lines enclosing all items of the telemetry system that were exposed to nuclear radiation. The other equipment was located in the nuclear reactor control room as support instrumentation. Discussion of the pressure and angular position transducers consititute another section of this report and will not be considered in detail here.

The philosophy underlying selection and testing of the telemetry system was to select reliable off-the-shelf components, analyze them for nuclear radiation tolerance, perform limited nuclear radiation oriented component modification, perform applicable nuclear radiation dynamic tests, and assess their usefulness in a nuclear radiation environment. The telemetering components shown in Figure 1 and 2 were selected because of past experience gained in Chance Vought's flight test program of the F8U. These units have proven highly reliable and stable under severe operating conditions, thus making the effects of nuclear radiation on their operating parameters more easily evaluated.

Nuclear radiation hardening (modification) of the telemetering system was limited to simple material and component changeout, with the exception of redesign of the Telechrome modulator circuit to eliminate a variable capacitor diode. Modifications were intentionally kept very simple, for it was one of the goals of this test to determine how basically stable the selected telemetering system was after minor modifications. No attempt was made to redesign the circuits for maximum radiation stability. A summary of the telemetering component modifications are listed in the following sections of the report.

2.2 Nuclear Radiation Exposure Test Conditions

The previously described telemetering system, shown in Figure 1, was irradiated in the East position of the three megawatt water moderated, enriched uranium 235 Ground Test Reactor at General Dynamics, Fort Worth, during the period of September 18 through 21,

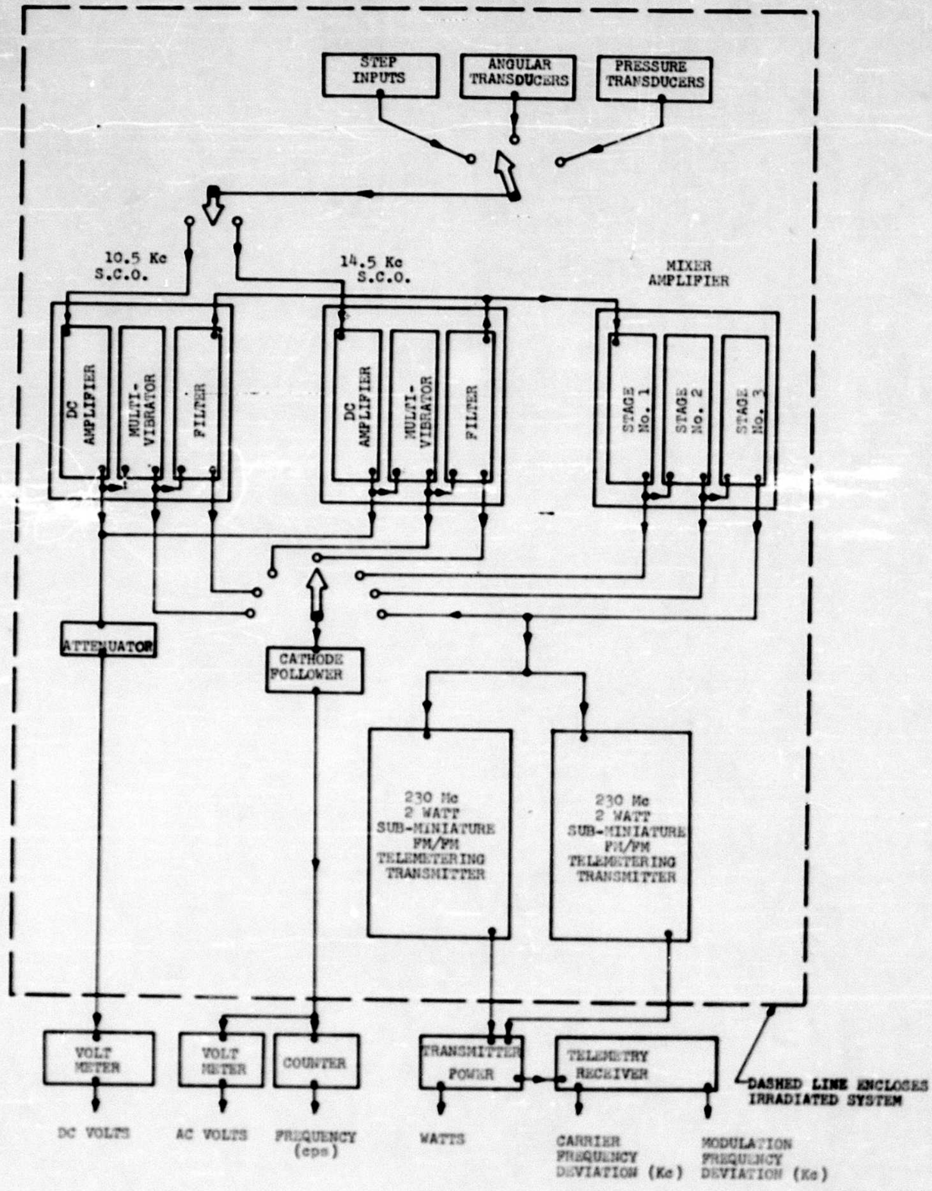


FIGURE 1. TELEMETRY SYSTEM

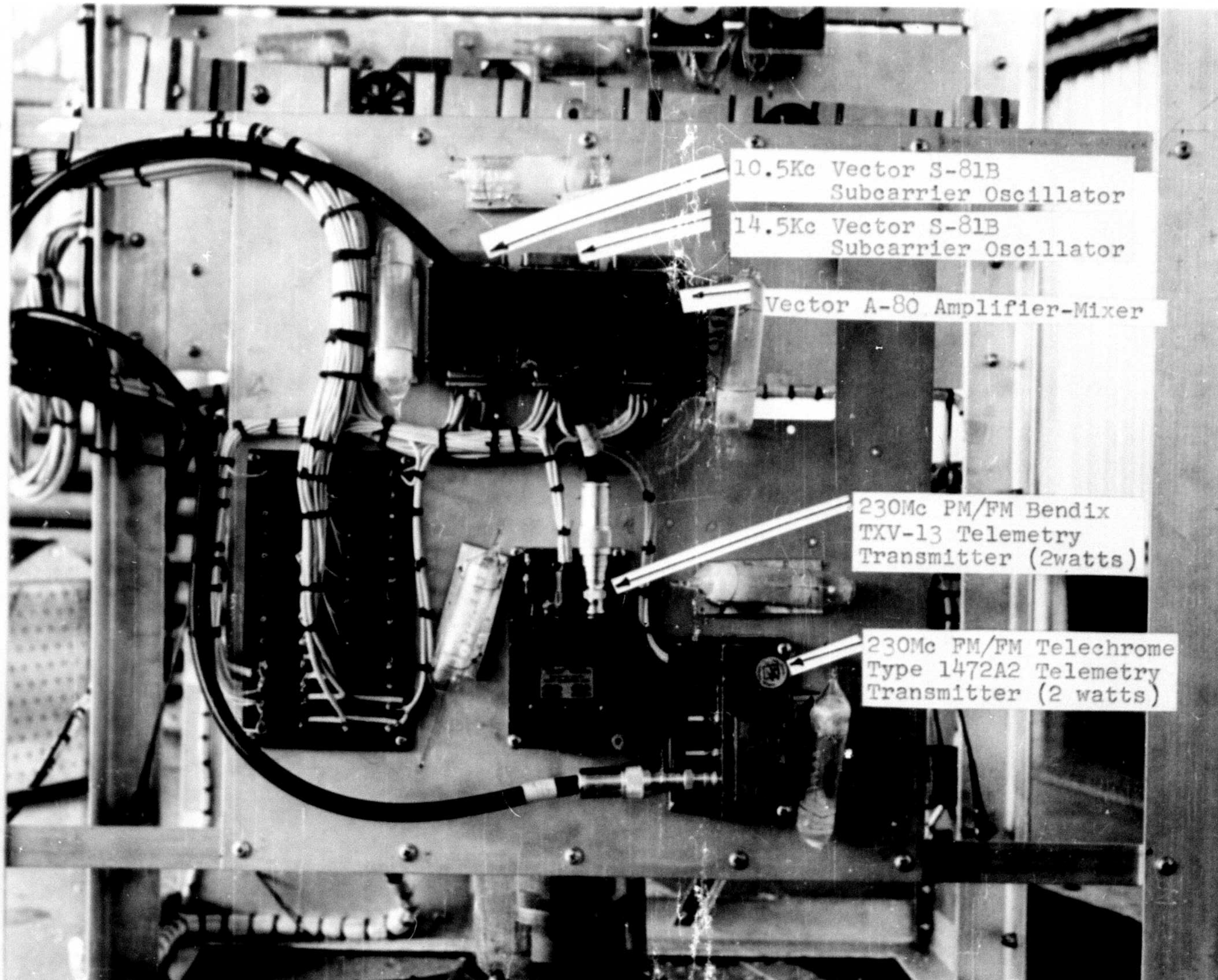


FIGURE 2 NUCLEAR IRRADIATION TELEMETRY TEST PANEL

1961 for a total exposure time of approximately 81 hours (Figure 3). The integrated neutron and gamma photon dose exposures for each of the telemetering components shown in Figure 1 differ slightly because of physical location relative to the nuclear reactor. Radiation exposures for each component are presented with the discussion of each component.

The air temperature environment of the east pallet varied from daytime to night time due to the change in ambient air, but the average temperature around the telemetering equipment was approximately 110°F. No attempt was made to control the temperature or humidity environment of the telemetering equipment, for the natural environment with the reactor at three megawatts is well within specification limits of -94°F to 239°F temperature range and 95 per cent humidity at 122°F. Environmental changes experienced by the telemetering components did not introduce any random or accumulative errors in measured output parameters.

Vibration contributions from the Lear actuator and Westinghouse generator helped provide a more realistic evaluation of the telemetering system, for in fact these components might be present in a typical flight test configuration. The relative physical relationships of the components would be different from those which existed in this test; however, a realistic vibration input was present.

2.3 Miniature Subcarrier Oscillator (Vector Type S-81B)

Conversion of signals, proportional to the various measurands in a multichannel system, into a complex modulating signal composed of variable tones is accomplished by the subcarrier oscillators. These oscillators may be any of four basic types, according to the method of modulation employed on the carrier. The type of oscillators used in the test were the voltage-controlled type. Voltage-controlled oscillators, as their name indicates, are modulated by a variable dc voltage. The dc voltage-controlled telemetering subcarrier oscillator converts intelligence in the form of dc voltage amplitudes into a frequency modulated subcarrier signal. Sources of the test dc voltage inputs to the 10.5 Kc and 14.5 Kc subcarrier oscillators are typical flight test instrumentation angular position transducers (potentiometer type), pressure transducers (potentiometer type), and step dc voltage inputs as illustrated in Figure 4. The schematic circuit diagrams for the 10.5 Kc and 14.5 Kc subcarrier oscillators are shown in Figures 5 and 6, respectively.

Major functional components of the subcarrier oscillator diagrams (Fig. 5 and 6) are:

a. Drift free, compensated dc amplifier

b. Free running, degenerative, positive bias multivibrator

c. Low-pass output filter

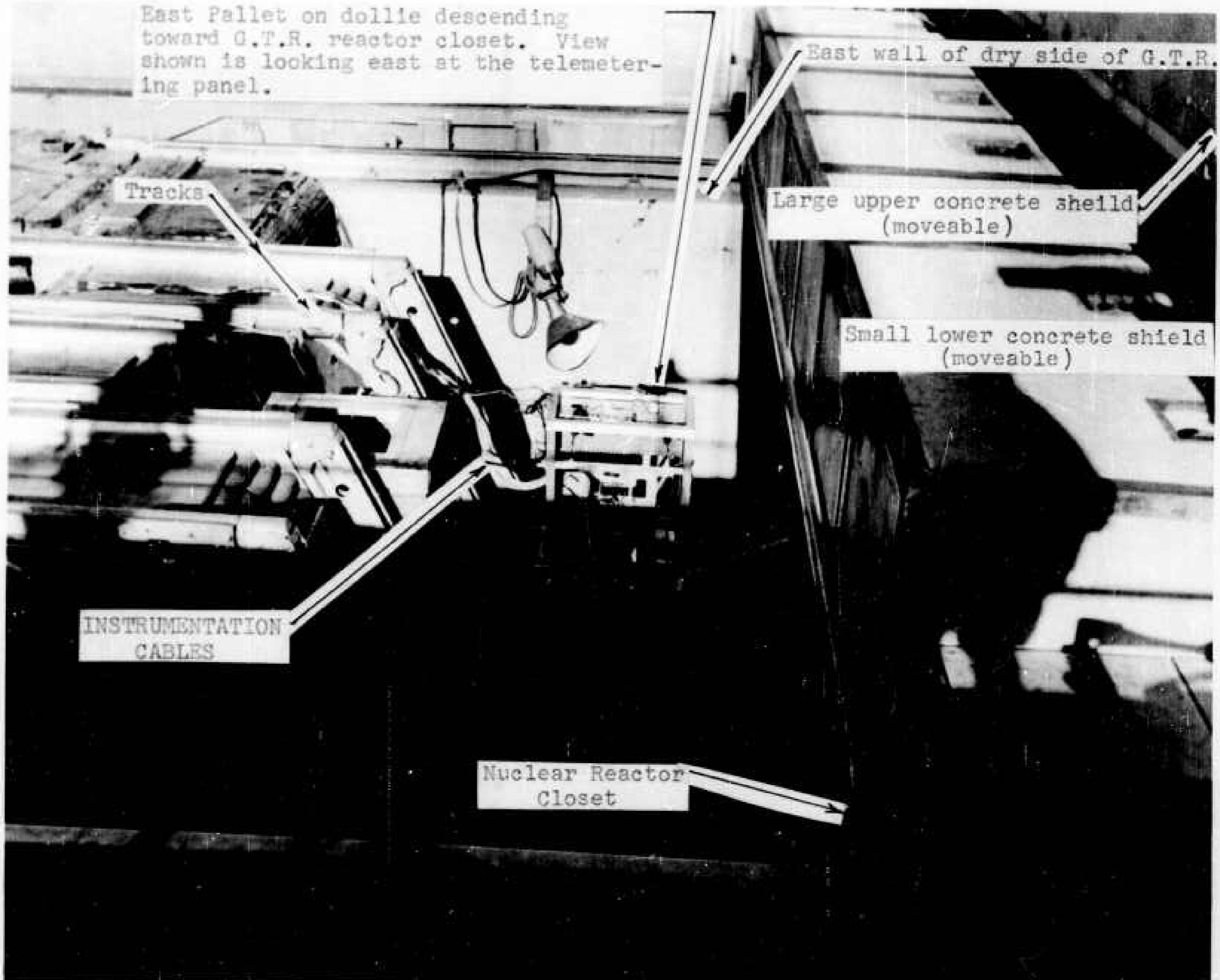


FIGURE 3 TELEMETRY TEST PANEL DESCENDING INTO THE GROUND TEST REACTOR

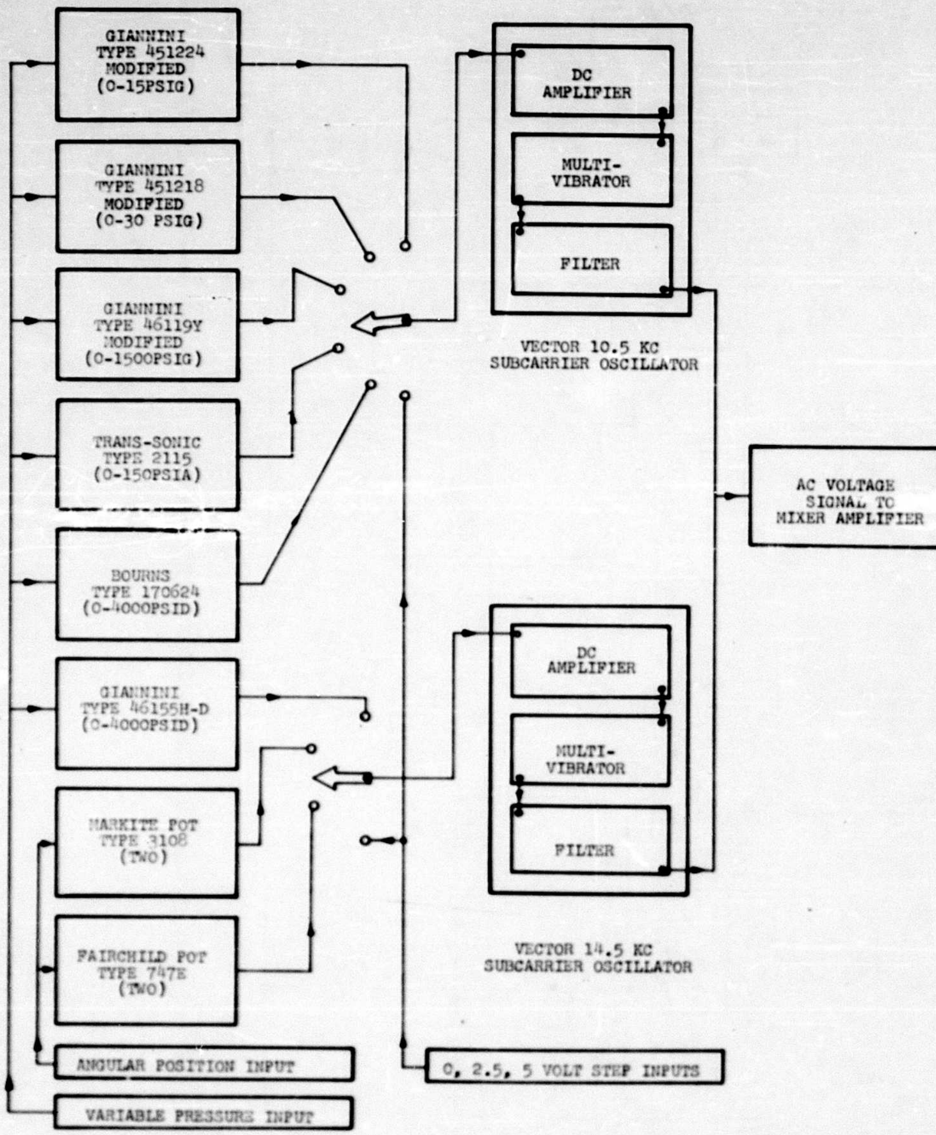
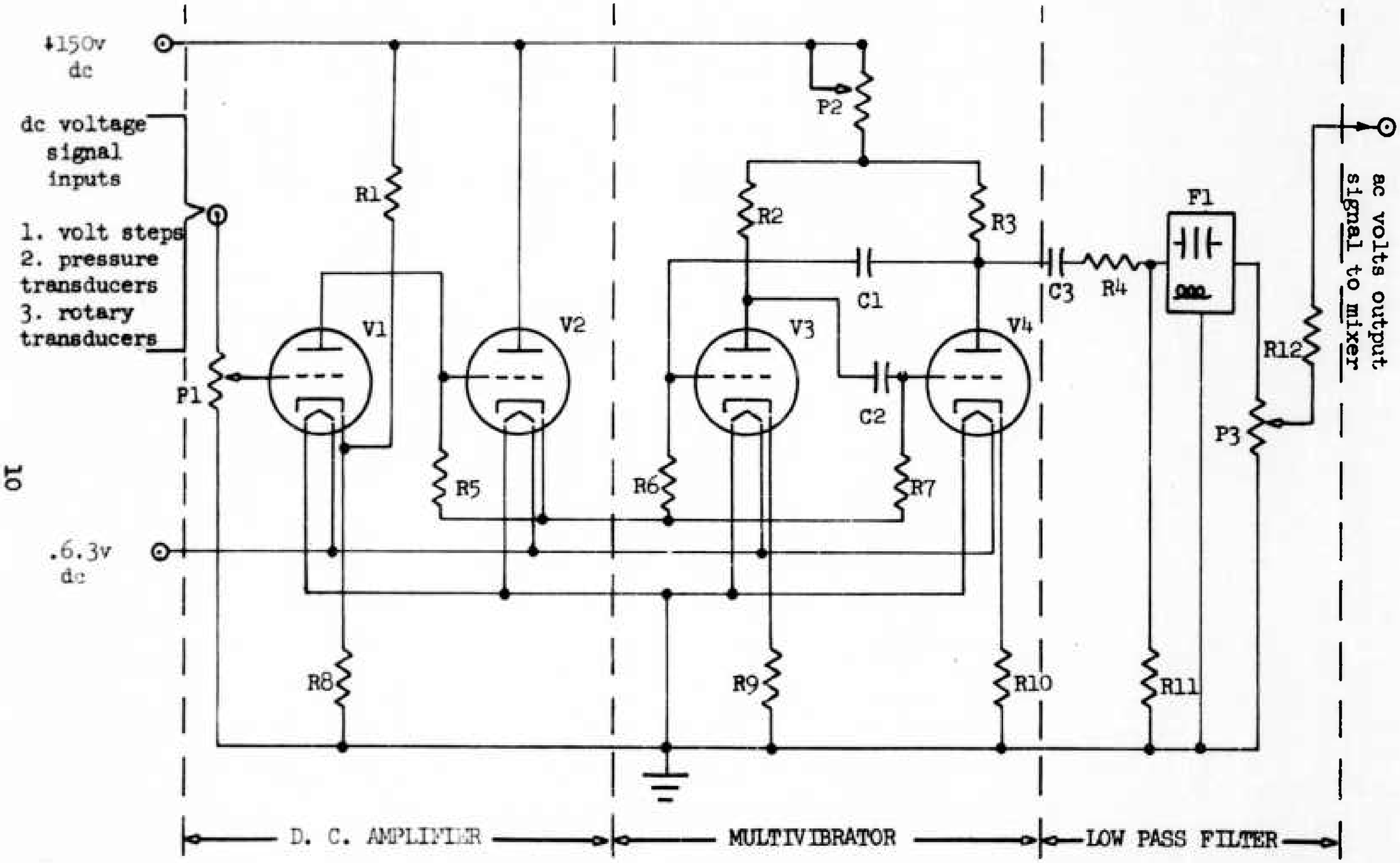
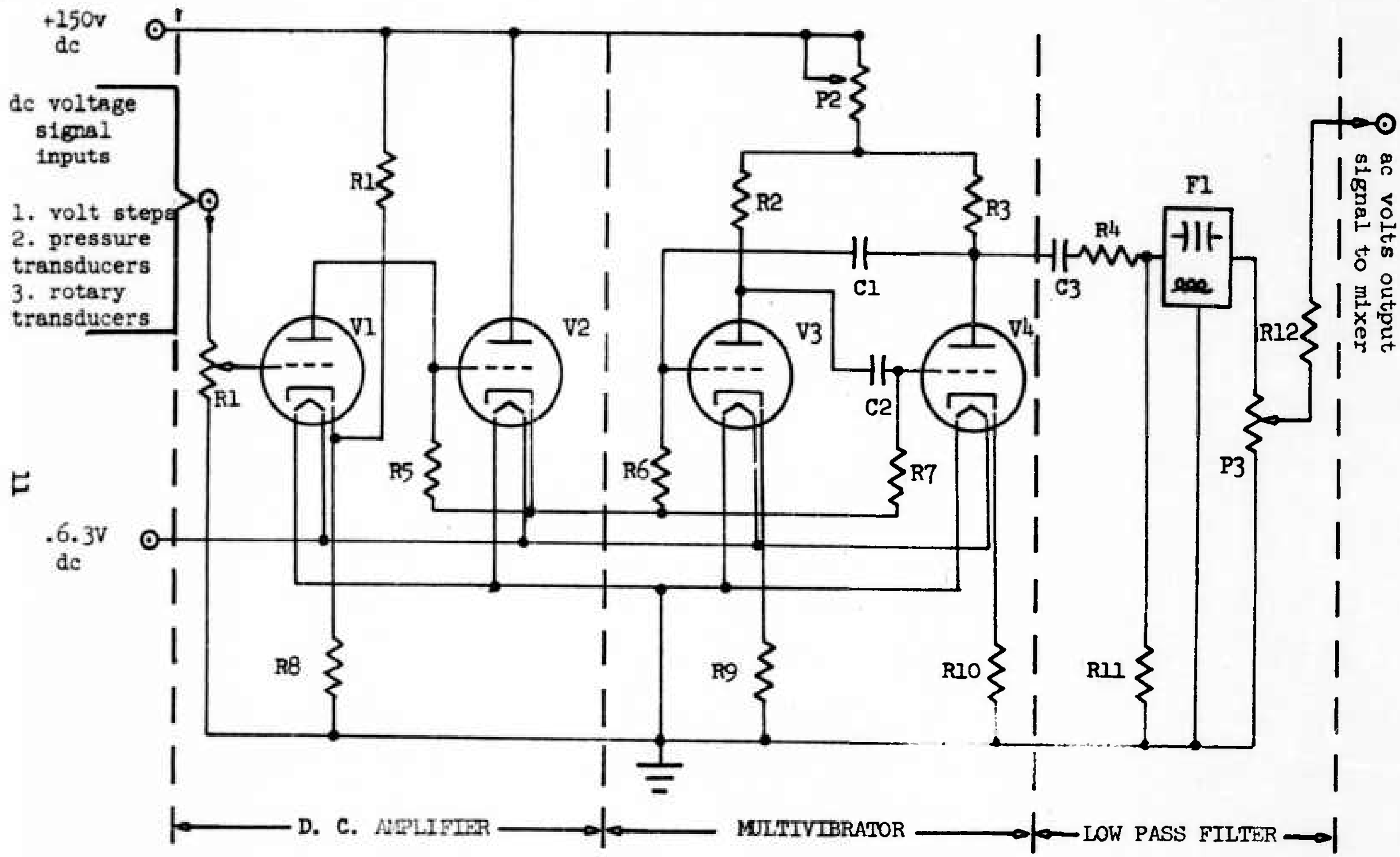


FIGURE 4 SIGNAL INPUTS TO SUBCARRIER OSCILLATORS



Note - Refer to Table 3 for Element Values

FIGURE 5 SCHEMATIC DIAGRAM FOR THE 10.5Kc VOLTAGE CONTROLLED SUBCARRIER OSCILLATOR, VECTOR MODEL S-81B



Note - Refer to Table 4 for Element values

FIGURE 6 SCHEMATIC DIAGRAM FOR THE 14.5 Kc VOLTAGE CONTROLLED SUBCARRIER OSCILLATOR VECTOR MODEL S-81B

The operation of the circuit is as follows: The variable dc input voltage to the triode V1 is amplified and applied to the grid of the modulator tube, V2, which results in alterations in the bias dc voltage to the free-running multivibrator, and hence in the frequency of operation. These output pulses form square waves, with many harmonics, which are fed through the low-pass filter, F1, to eliminate the harmonics. Typical performance characteristics for the Vector Type S-81B miniature subcarrier oscillator are:

a. Modulation linearity, 0.75 %

b. Output, 2.5 volts rms minimum

c. Modulation sensitivity, ≮ 7.5 % deviation for 0 to 5 vdc input

d. Output impedance, 47,000 ohms

Complete specifications are contained in Appendix B1. The only difference between the 10.5 Kc and 14.5 Kc subcarrier voltage controlled oscillator are the values of capacitors C_1, C_2 (Fig. 5) and C_1, C_2 (Fig. 6) in the multivibrator.

A nuclear radiation effects evaluation of the subcarrier oscillator was performed to assess what modifications were feasible to extend its operational life in a nuclear radiation environment. As previously stated, only minor modification was considered feasible for the test. Materials and components replacement modification, detailed in Table 1, was the same for the 10.5 Kc and 14.5 Kc subcarrier oscillators.

TABLE 1

Nuclear Radiation Effects Modification of the Subcarrier Oscillators

Electronic Element	Original Element		Replacement Element	
	Material Description	Nuclear Radiation Functional Threshold	Material Description	Nuclear Radiation Functional Threshold
Electrical wire insulation	Teflon	1.0×10^7 ergs/gm-(C)	Polyvinyl-chloride and Fiberglass sleeving	2.0×10^{10} ergs/gm-(C)
Capacitor	paper - .01 mfd, 200v Aerovox	1.1×10^8 ergs/gm-(C)	Mylar - .01 mfd, 200v Goodall	1.2×10^{10} ergs/gm-(C)

TABLE 1 (Continued)

Electronic Element	Original Element		Replacement Element	
	Material Description	Nuclear Radiation Functional Threshold	Material Description	Nuclear Radiation Functional Threshold
Resistor	Molded carbon with Boron-5.1K Ohm, 0.5W I.R.C.	7.0×10^7 ergs/gm-(C)	Deposited carbon 5.1K ohm, 0.5W I.R.C.	1.8×10^{11} ergs/gm-(C)
Tube, Electron	Four-glass envelope subminiature GE 6111	1.0×10^{16} n/cm^2*	Four-glass envelope subminiature GE 6111 Five Star	5.0×10^{16} n/cm^2*

A large part of the electrical hookup wire was Teflon insulated which would not withstand the expected 5×10^{10} ergs/gm-(C) gamma exposure; hence a polyvinylchloride insulated electrical hookup wire was substituted. Where space permitted, a fiberglass sleeving was placed over the polyvinylchloride insulation to minimize shorting, should the insulation melt. The melting point for polyvinylchloride is approximately 200°F, and since the packing density was increased inside the SCO's due to replacement of the material, hot spots in excess of 200°F possibly would occur. Other modifications were: mylar substituted for paper capacitors, deposited carbon substituted for molded carbon (with boron) in resistors, and G.E. 6111 Five Star substituted for G.E. 6111 glass envelope electron tubes. The substituted electronic elements were standard off-the-shelf elements with an established history of reliable applications. This fact assists in separating normal operational failures from nuclear radiation induced component failures. These modifications qualify the SCO's for the 1×10^{10} ergs/gm-(C) gamma, and 1×10^{16} n_f/cm^2* as set forth as a basic goal of modification.

Output voltage of the three components of the SCO's; drift free, compensated dc amplifier; free running degenerative, positive bias multivibrator; and low pass output filter were instrumentated so each could be monitored during the irradiation. Parameters monitored during the test are presented in Table 2 with values taken during instrumentation base line data run.

* n is used throughout this report to denote thermal neutrons with neutron energies less than .025 ev.

* n_f is used throughout this report to denote fast neutrons with energies larger than 1 Mev ($E > 1$ Mev).

TABLE 2

ABSTRACT OF TELEMETERING DATA SHEET FOR THE SUBCARRIER OSCILLATORS

Step Input Volts (dc)	10.5 Kc S C O					
	dc Amplifier Output (Volts)	Multivibrator Output		Filter Output		Distortion (%)
		Volts (ac)	Freq. (cps)	Volts (ac)	Freq. (cps)	
0	76.5	1.27	11160	.55	11150	-
2.5	69.4	1.40	10531	.41	10523	1.05
5.0	62.1	1.60	9895	.78	9895	-
	14.5 Kc S C O					
0	77.9	.96	15360	.40	15350	-
2.5	71.2	1.10	14506	.42	14494	2.5
5.0	64.2	1.30	13669	.52	13654	-

2.3.1 Subcarrier Oscillator, 10.5 Kc, (Vector Model S-81B)

Stable operation of the 10.5 Kc SCO was achieved with the test pallet in place adjacent to the reactor in the east position prior to reactor start up. There was no noticeable change in SCO parameters as the reactor was brought up to power. The SCO functioned 49 hours of the 80.73 hours of reactor operation. Total nuclear radiation exposure accumulated during the 237.2 Mw hours of reactor operation was 9.6×10^{10} ergs/gm-(C) and 3.1×10^{16} n_f/cm^2. Dosimetry data presented in Table IVA for the 10.5 Kc SCO was reduced and put in graph form, as presented in Figure 7.

Amplifier Stage, 10.5 Kc SCO Output voltage of the dc amplifier showed little variation until signal failure which occurred after 49 hours of reactor operation (Fig. 8) and an exposure of 5.7×10^{10} ergs/gm-(C) gamma and 1.9×10^{16} n_f/cm^2 (Fig. 7). Post irradiation test evaluation of the amplifier revealed that the R1 resistor shown in circuit diagram, Figure 5, had a significant increase in resistance due to interaction of nuclear radiation energy with resistor materials. Details of this type of interaction are discussed at length in

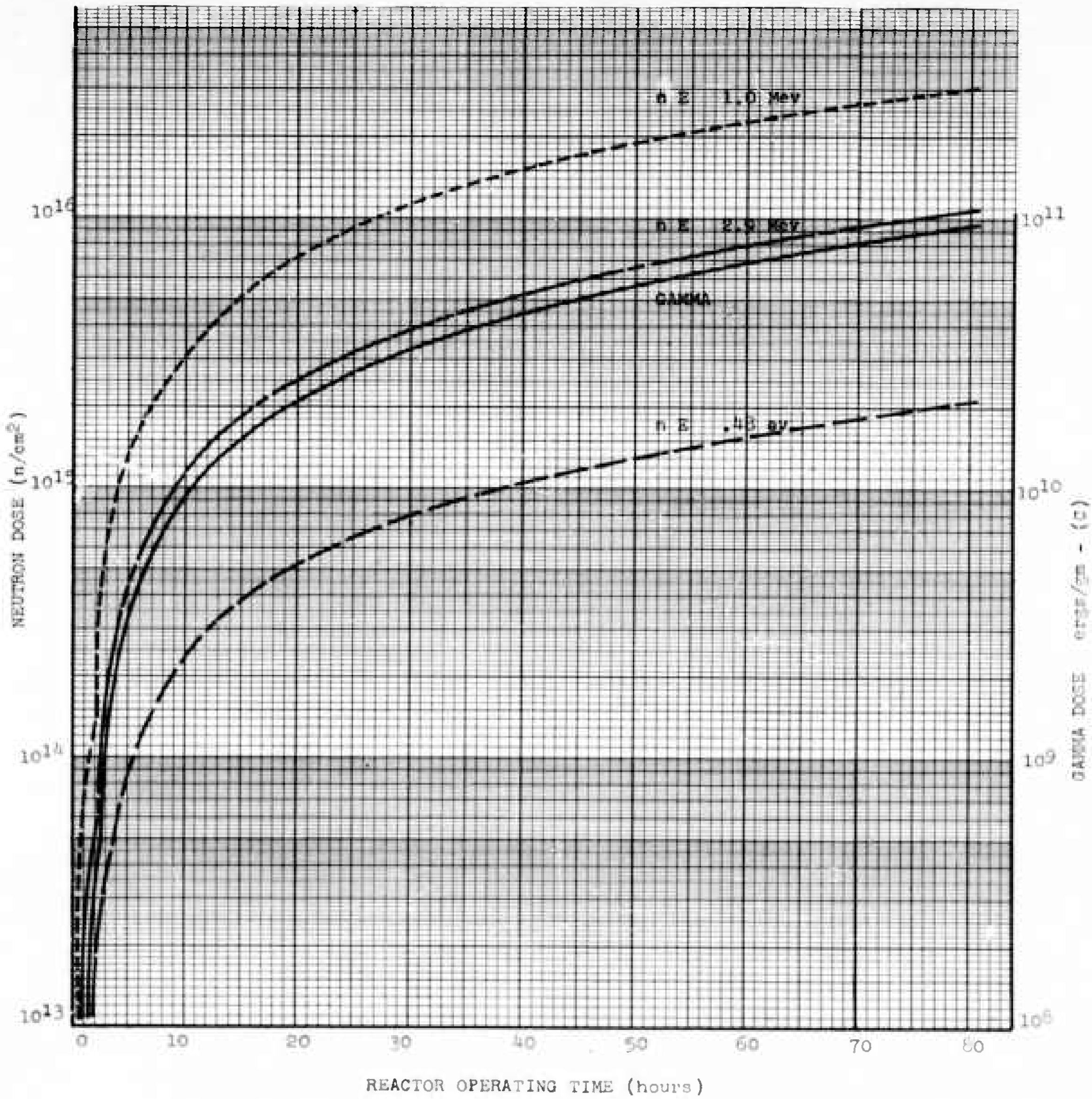


FIGURE 7 NUCLEAR RADIATION EXPOSURE FOR 10.5 KC SUBCARRIER OSCILLATOR

Notes:
1. Output Voltage Based upon a 2.5 Volt dc Input
2. See Figure 7 for Nuclear Radiation Exposure
3. See Figure 5 for Wiring Diagram

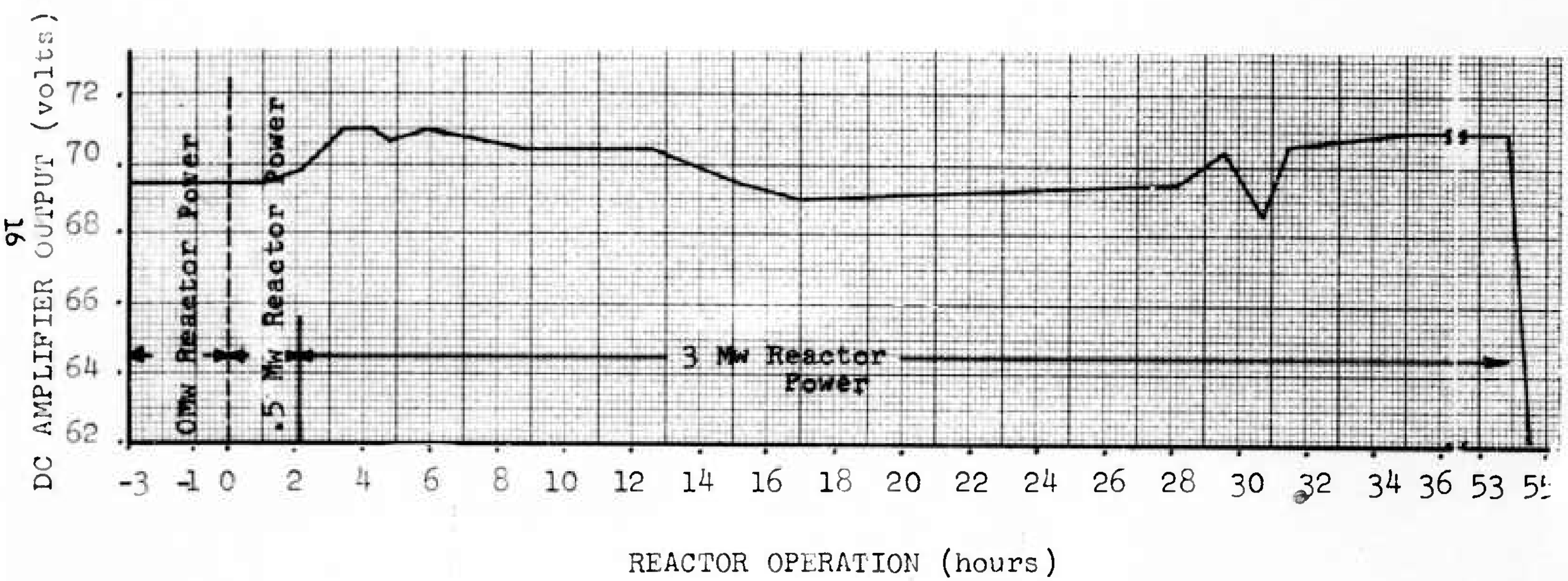


FIGURE 8 DC AMPLIFIER OUTPUT (10.5 Kc SUBCARRIER OSCILLATOR)

Appendix C. Failure of the R1 resistor at an exposure dose of 5.7×10^{10} ergs/gm-(C) is premature by a factor of 3, for in general a deposited carbon resistor will be within specification limits after an exposure of 1.8×10^{11} ergs/gm-(C). This discrepancy in expected behavior is assumed to be related to a combination of manufacturing tolerances, statistical failure, and unknown environmental conditions. R1 was an IRC 240 K ohm ±1%, 0.5 watt deposited carbon resistor (Ref. Table 3). The rest of the electronic elements in the dc amplifier did not show any significant changes.

Multivibrator Stage, 10.5 Kc SCO Output parameters, frequency and voltage, were stable during the pre-irradiation base line data run while in position adjacent to the reactor. Frequency was stable until failure occurred after 2.9 hours of operation. Small output voltage fluctuations occurred during the first hour of operation with a negative 8.3% decrease occurring after 2.15 hours (Fig. 9). Output voltage decreased to 0 after 2.9 hours of reactor operation. Post irradiation tests revealed that multivibrator failure was caused by failure of resistors R6 and R7, Figure 5. They were 330K ohm ±1%, 0.5 watt, Reon wire wound encapsulated resistors. Both resistors had increased in resistance to 5 M ohms by the end of the test. Exact resistance at the time of multivibrator failure is not known, but a large enough change occurred to cause output voltage to decrease to zero after 2.9 hours and a nuclear radiation exposure of 1.5×10^9 ergs/gm-(C) and 5.0×10^{14} n_f/cm^2 (Ref. Fig. 7). Wire wound type resistors are expected to function normally after an exposure of 1.0×10^{17} n_f/cm^2; however, post irradiation evaluation revealed that the resistors were wound on an organic spool, which would reduce their tolerance to nuclear radiation. It was concluded that resistors No. 6 and 7 (Fig. 5) developed an open circuit as a result of the spools' increasing in size and causing wires to break.

Other electronic elements in the multivibrator were not significantly changed at the time of the post irradiation test. Normal operating parameters were restored by replacing resistors R6 and R7, Figure 5.

Low-Pass Output Filter Stage, 10.5 Kc SCO The filter is an electrical circuit network composed of inductors and capacitors designed to have specific characteristics with respect to the transmission and attenuation of various frequencies applied by the multivibrator stage (Ref. Appendix B). It is an unbalanced low pass filter that passes all frequencies below upper band cut-off frequency.

Up until failure of the multivibrator stage at 2.9 hours of reactor operation, the low pass filter was functioning correctly. Evidence thus indicates that, at the time the input signal to the filter from the multivibrator was terminated, elements of the filter had not degraded enough to effect the filter output signal. Post irradiation evaluation tests revealed that effectively the filter had degraded to

TABLE 3

POST IRRADIATION EVALUATION FOR COMPONENTS OF THE
10.5 Kc SUBCARRIER VOLTAGE CONTROLLED OSCILLATOR
VECTOR MODEL S-81B
(REFERENCE SCHEMATIC DIAGRAM, FIGURE 5)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Pot	P1	1M ohm	Ohmite	AS	Molded composition	Insignificant resistance change
Pot	P2	25K	Ohmite	AS	Molded composition	Insignificant resistance change
Pot	P3	75K	Ohmite	AS	Molded composition	Insignificant resistance change
*Resistor	R1	240K ohm	IRC	DCC	Deposited Carbon	1.5M ohm - Caused DC Amp. failure
*Resistor	R2	51K ohm	IRC	DCC	Deposited Carbon	Insignificant resistance change
*Resistor	R3	51K ohm	IRC	DCC	Deposited Carbon	Insignificant resistance change
*Resistor	R4	180K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R5	5.1K ohm	IRC	DCC	Molded deposited carbon	Insignificant resistance change
*Resistor	R6	330K ohm	Reon	TL23	Wire wound encapsulated	5M ohm - Caused multivibrator failure
*Resistor	R7	330K ohm	Reon	TL23	Wire wound encapsulated	5M ohm - Caused multivibrator failure
*Resistor	R8	3.6K ohm	IRC	DCC	Deposited Carbon	Insignificant resistance change

TABLE 3 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
*Resistor	R9	200K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R10	200K ohm	IRC	MDA	Molded Deposited carbon	Insignificant resistance change
*Resistor	R11	180K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R12	50K ohm	IRC	DCC	Deposited carbon	Insignificant resistance change
**Capacitor	C1	180 mmfd	El-Menco	DM-19	Dip coated silvered mica	Insignificant capacitance change
**Capacitor	C2	180 mmfd	El-Menco	DM-19	Dip coated silvered mica	Insignificant capacitance change
**Capacitor	C3	.01 mfd	Goodall		Metalized Mylar	Insignificant capacitance change
Tube, Electron	V1		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change
Tube, Electron	V2		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change
Tube, Electron	V3		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change
Tube, Electron	V4		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change

TABLE 3 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Filter	F1	1.7KC 7.5%	Vector	Low Pass	Aerovox 2% Mica capacitors inductor - wire on nylon spools	Nuclear radiation induced failure - capacitors shorted to ground

* All Resistors are 0.5 Watt ±1%

** All Capacitors are 200 volts

Notes:
1. Output Voltage Based Upon A 2.5 Volt dc Amplifier Input
2. See Figure 7 For Nuclear Radiation Exposure
3. See Figure 5 For Wiring Diagram

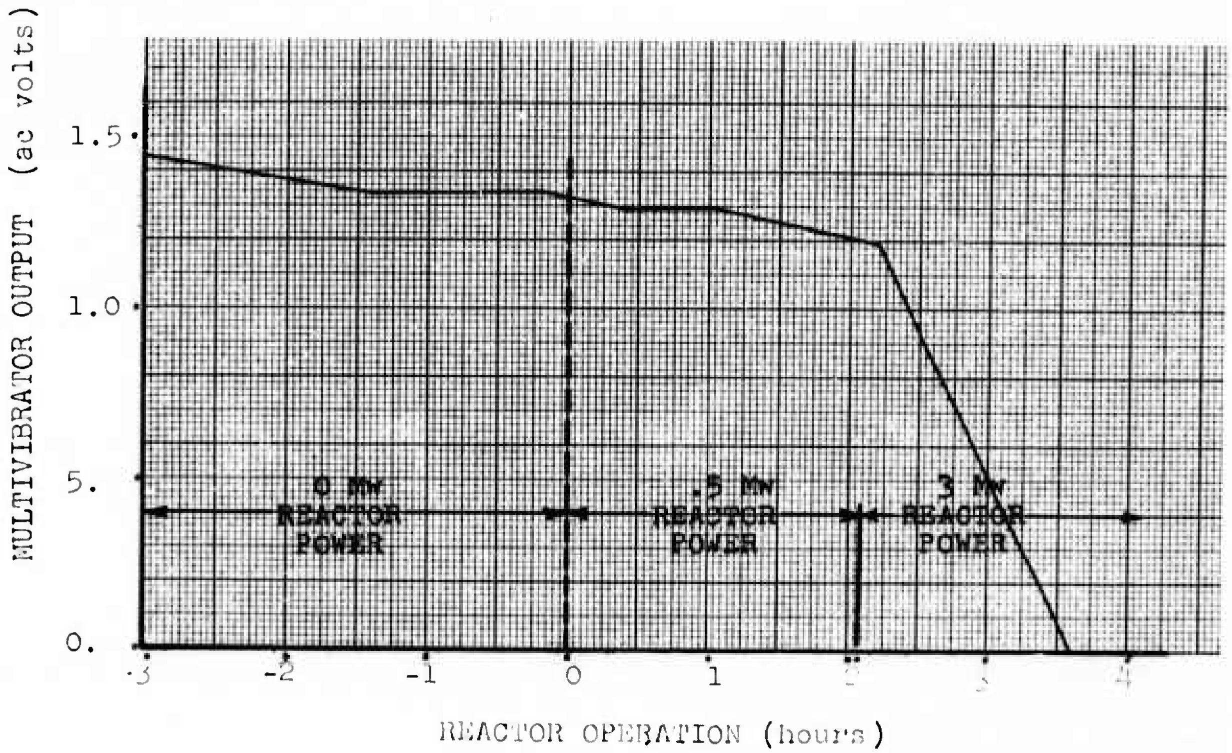


FIGURE 9 MULTIVIBRATOR OUTPUT (10.5 Kc SUBCARRIER OSCILLATOR)

the point that it did not act like a filter, but as an ac short to ground and attenuator. It would bypass all frequencies applied at input. It was not established what electronic elements caused this change, for the filter was potted in place. Attempts at disassembly destroyed the components as far as parameter evaluation was concerned. It was concluded that nuclear induced degradation of the mica capacitors caused failure of the low pass filter. In general, filters should be free of potting compound during a nuclear radiation effects evaluation so components can be evaluated separately. An alternate would be to incorporate test leads in filter circuit and then pot.

2.3.2 Subcarrier Oscillator, 14.5 Kc (vector Model S-81B)

Stable operation of the 14.5 Kc SCO was achieved with the test pallet in place adjacent to the reactor in the east position prior to reactor start up. There was no noticeable change in SCO parameters as the reactor was brought up to power. The SCO functioned for 30.0 hours of the 80.73 hours of reactor operation (Ref. Fig. 10). Total nuclear radiation exposure accumulated during the 237.2 Mw hours of reactor operation was 8.0×10^{10} ergs/gm-(C) and 2.8×10^{16} n_f/cm^2. Dosimetry data presented in Table 4A for the 14.5 Kc SCO was reduced and put in graph form as presented in Figure 11. A complete description of elements shown in Figure 6, Schematic Diagram of 14.5 Kc SCO, with failure notes is presented in Table 4. This table represents the modified SCO as it was irradiated.

Amplifier Stage, 14.5 Kc SCO A stable output voltage was observed for 2.1 hours of reactor operation. The voltage became unstable after that time and finally went to zero after 30 hours of reactor operation (Ref. Fig. 10). Failure of the amplifier was caused by a 2 M ohm increase in resistance of the IRC 5.1 K ohm ±1%, 0.5 watt, molded deposited carbon resistor R5 (Fig. 5). This failure occurred after a nuclear radiation exposure of 2.9×10^{10} ergs/gm-(C) and 1.0×10^{16} n_f/cm^2 and is thought to be a result, in part, of the nuclear radiation interaction with the resistor. Failure of the resistor was premature by a factor of 6 as compared to similar deposited carbon resistors. This variation in expected behavior is assumed to be related to a combination of manufacturing tolerances, statistical failure, and undefined environmental conditions. The rest of the electronic elements in the dc amplifier did not show any significant changes.

Multivibrator Stage, 14.5 Kc SCO Output parameters, frequency and voltage, were stable during the pre-irradiation base line data run while in position adjacent to the reactor. The frequency remained stable until failure occurred after 2.9 hours of reactor operation, which was equivalent to a nuclear radiation exposure of 1.3×10^9 ergs/gm-(C) and 4.0×10^{14} n_f/cm^2. A noticeable decrease in voltage output occurred after the reactor was brought up to power. Comparison of Figure 12 with Figure 9 shows that the two multivibrators, 10.5 Kc and 14.5 Kc, had about the same voltage failure. Post irradiation

Note: 1. Output Voltage based upon a 2.5 Volt dc Input
2. See Figure 11 for Nuclear Radiation Exposure
3. See Figure 6 for Wiring Diagram

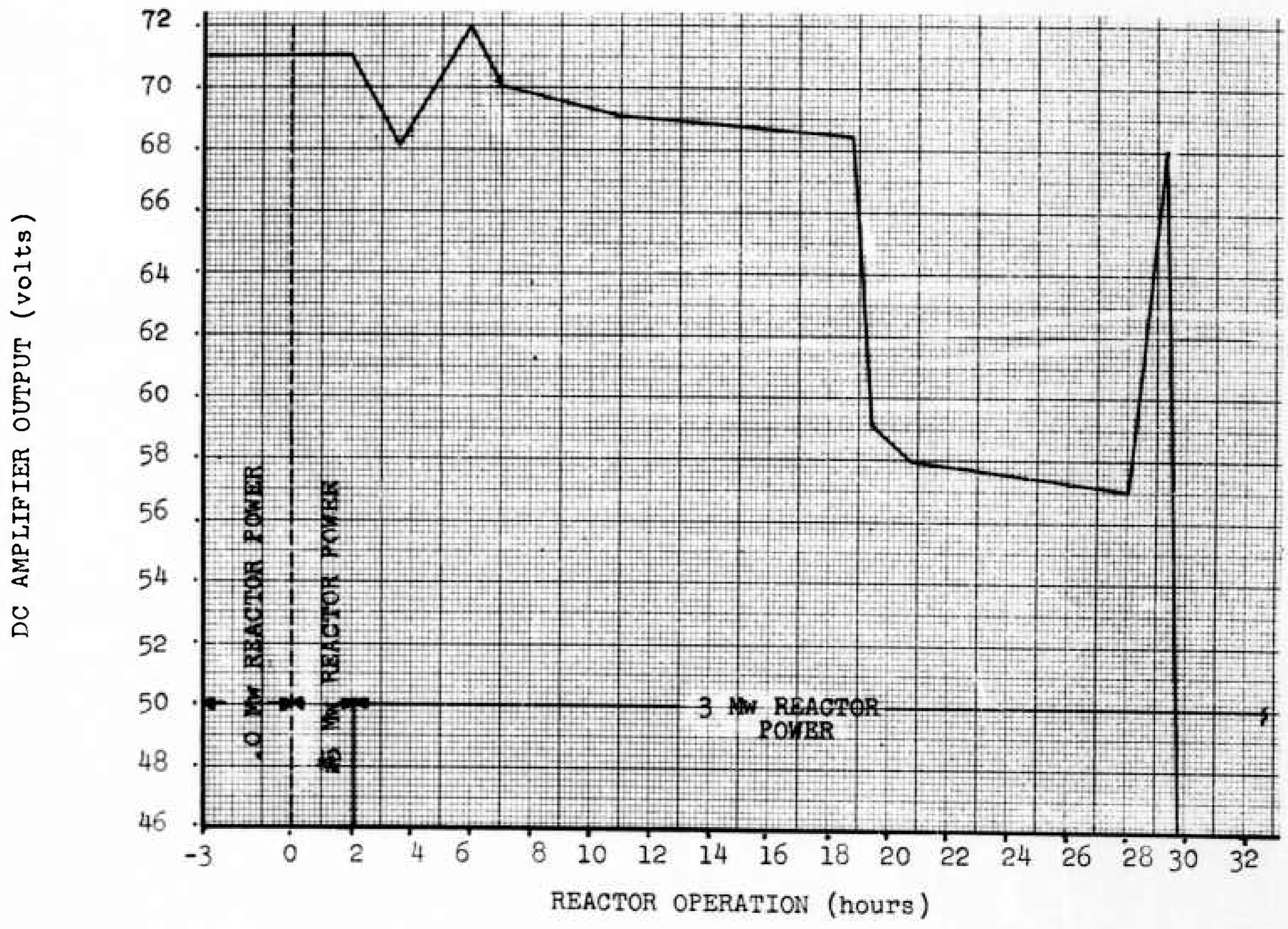


FIGURE 10 DC AMPLIFIER OUTPUT (14.5 Kc SUBCARRIER OSCILLIATOR)

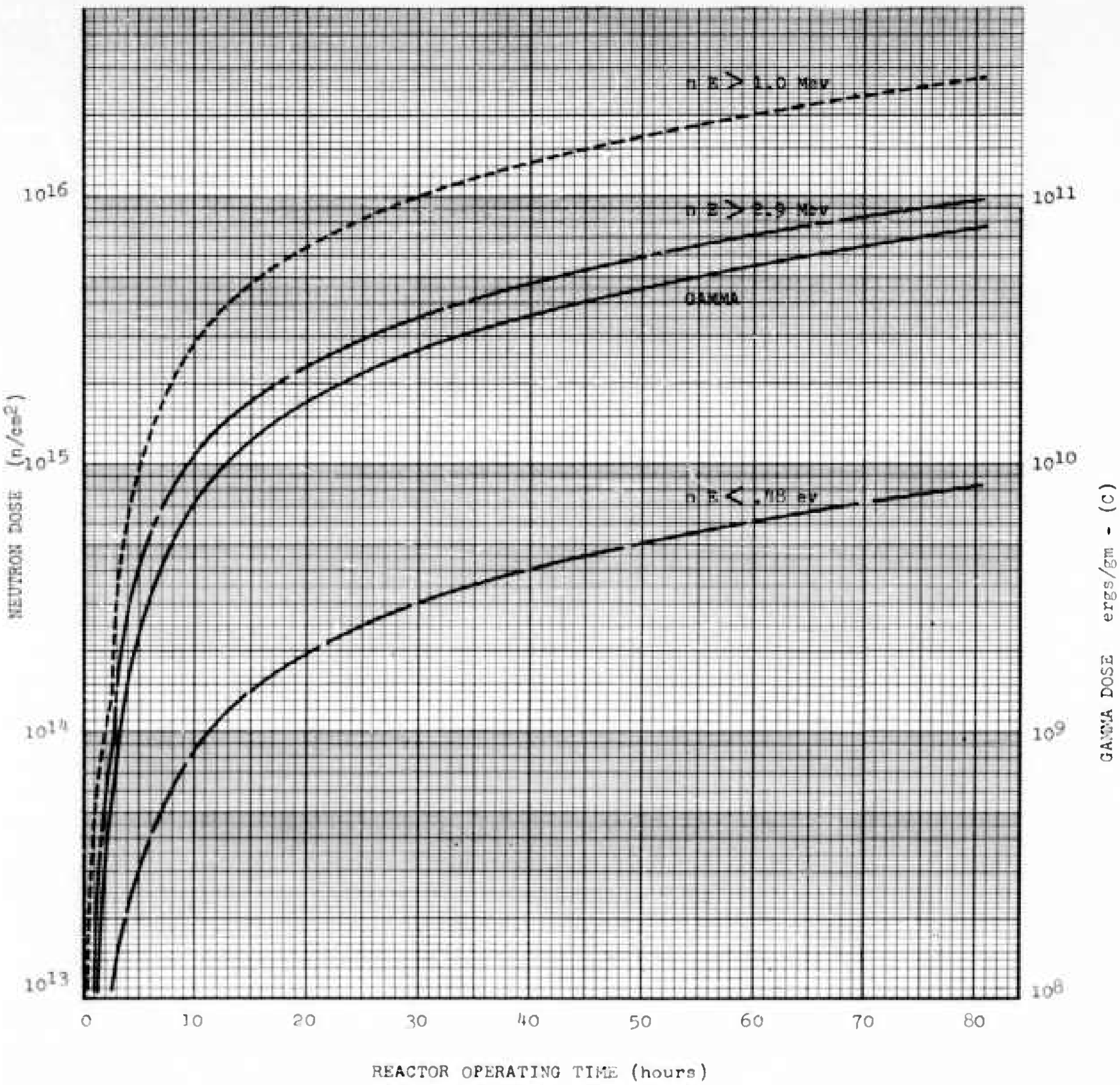


FIGURE 11 NUCLEAR RADIATION EXPOSURE FOR THE 14.5 MC SUBCARRIER OSCILLATOR AND MIXER AMPLIFIER

TABLE 4

POST IRRADIATION EVALUATION FOR COMPONENTS OF THE 14.5 Kc SUBCARRIER VOLTAGE CONTROLLED OSCILLATOR VECTOR MODEL S-81B

(REFERENCE SCHEMATIC DIAGRAM, FIGURE 6)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Pot	P1	1M ohm	Ohmite	AS	Molded composition	Insignificant resistance change
Pot	P2	25K ohm	Ohmite	AS	Molded composition	Insignificant resistance change
Pot	P3	75K ohm	Ohmite	AS	Molded composition	Insignificant resistance change
*Resistor	R1	240K ohm	IRC	DCC	Deposited carbon	Insignificant resistance change
*Resistor	R2	51K ohm	IRC	DCC	Deposited carbon	45K ohm - Slight change
*Resistor	R3	51K ohm	IRC	DCC	Deposited carbon	5M ohm - Contributed to Multi-vib. failure
*Resistor	R4	180K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R5	5.1K ohm	IRC	DCC	Molded deposited carbon	2M ohm - Caused DC Amp. failure
*Resistor	R6	330K ohm	Daven		Wire wound encapsulated	Insignificant resistance change
*Resistor	R7	330K ohm	Reon	TL23	Wire wound encapsulated	open - Contributed to Multi-vib. failure
*Resistor	R8	3.6K ohm	IRC	DCC	Deposited carbon	Insignificant resistance change

TABLE 4 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
*Resistor	R9	200K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R10	200K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R11	180K ohm	IRC	MDA	Molded deposited carbon	Insignificant resistance change
*Resistor	R12	50K ohm	IRC	DCC	Molded deposited carbon	Insignificant resistance change
**Capacitor	C1	130 mmfd	El-Menco	DM-19	Dip coated silvered mica	Insignificant capacitance change
**Capacitor	C2	130 mmfd	El-Menco	DM-19	Dip coated silvered mica	Insignificant capacitance change
**Capacitor	C3	.01 mfd	Goodall		Metalized mylar	Shorted
Tube, Electron	V1		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change
Tube, Electron	V2		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change
Tube, Electron	V3		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change
Tube, Electron	V4		GE	6111 5 Star	Glass envelope sub miniature	Insignificant change

TABLE 4 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Filter	F1	1.7Kc 7.5%	Vector	Low Pass	Aerovox 2% Mica capacitors inductor - wire on nylon spool	Nuclear Radiation induced failure - capacitors shorted out and acted like an attenuator

* All Resistors are 0.5 Watt ±1%

** All Capacitors are 200 volts

tests revealed that multivibrator failure was caused by failure of resistors R3 and R7 (Fig. 6). R3 was a 51 K ohm ±1%, 0.5 watt IRC deposited carbon resistor and R7 was a 330 K ohm ±1%, 0.5 watt, Reon wire wound resistor (Table 4). Effectively both resistors had developed a resistance equivalent to an open circuit at the end of the test, 80.73 hours and a nuclear radiation exposure of 8.0×10^{10} ergs/gm-(C) and 2.8×10^{16} n/cm^2. However, as pointed out before, failure occurred after 2.9 hours; thus the properties of the resistors at the end of the test were different from those at the time of multivibrator failure. R7 in this circuit was the same as R7 in the 10.5 Kc multivibrator and failure time and exposed gamma dose were almost identical. This fact indicates that the nuclear induced R3 resistor failure could have occurred after failure of the multivibrator due to the R7 Reon wire wound resistor opening up. Data are inadequate to evaluate a relative failure point of the R3 deposited carbon resistor with accepted standards.

Other electronic elements in the multivibrator were not significantly changed at the time of the post irradiation test. Normal operating parameters were established by replacing resistors R3 and R7 (Table 4).

Low-Pass Output Filter Stage, 14.5 Kc SCO The reader is referred to the discussion of the 10.5 Kc SCO filter, for the post irradiation evaluation of both filters was the same.

2.4 Miniature Mixer Amplifier (Vector Type A-80)

The miniature mixer amplifier is a high-gain, three stage, feedback audio amplifier. It is used for summing and amplifying the ac voltage outputs of the Vector Type S-81B 10.5 Kc and 14.5 Kc Subcarrier Oscillators. Typical performance characteristics for the Vector Type A-80 miniature mixer amplifier are:

a. Output impedance, cathode follower output

b. Harmonic distortion, less than 5%

c. Frequency response, flat within ± 0.5 db from 100 cps to 100 K cps

d. Gain, adjustable to approximately 20 to 10 volts rms maximum output

Complete specifications are contained in Appendix B2. The mixer output ac voltage signal was fed to either the Bendix or Telechrome telemetering transmitters. The relationship of the mixer amplifier is

Notes:
1. Output Voltage Based Upon a 2.5 Volt dc Input
2. See Figure 11 For the Nuclear Radiation Exposure
3. See Figure 6 For Wiring Diagram

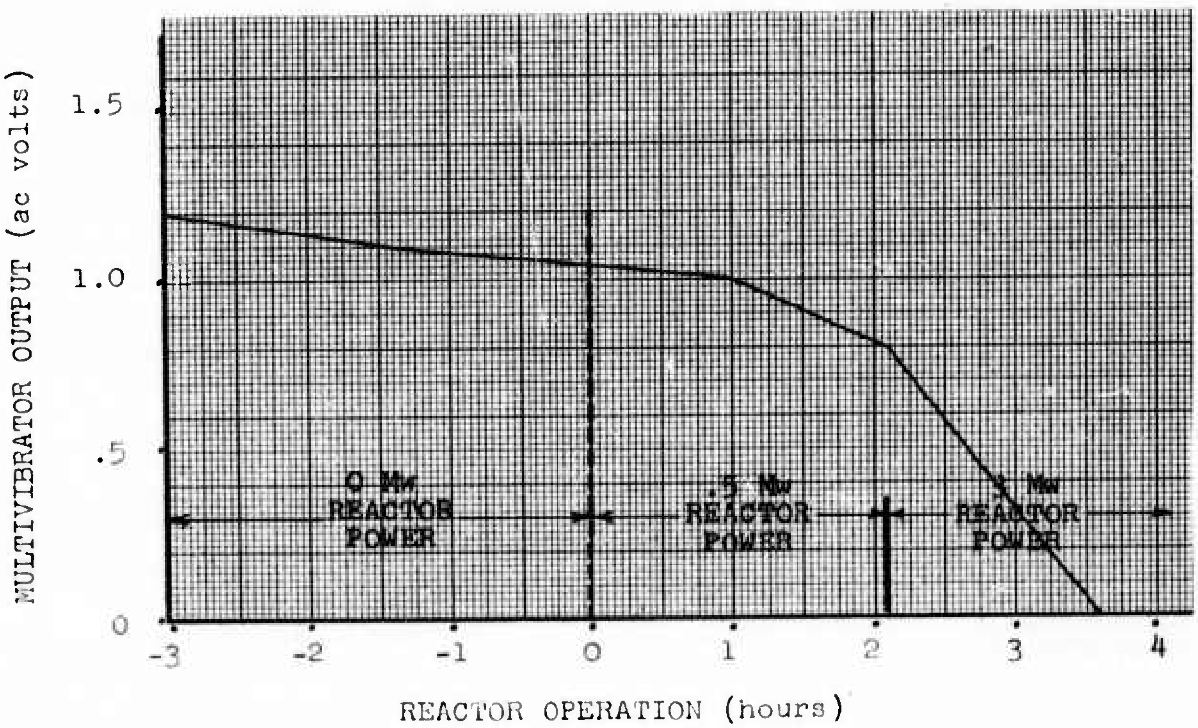
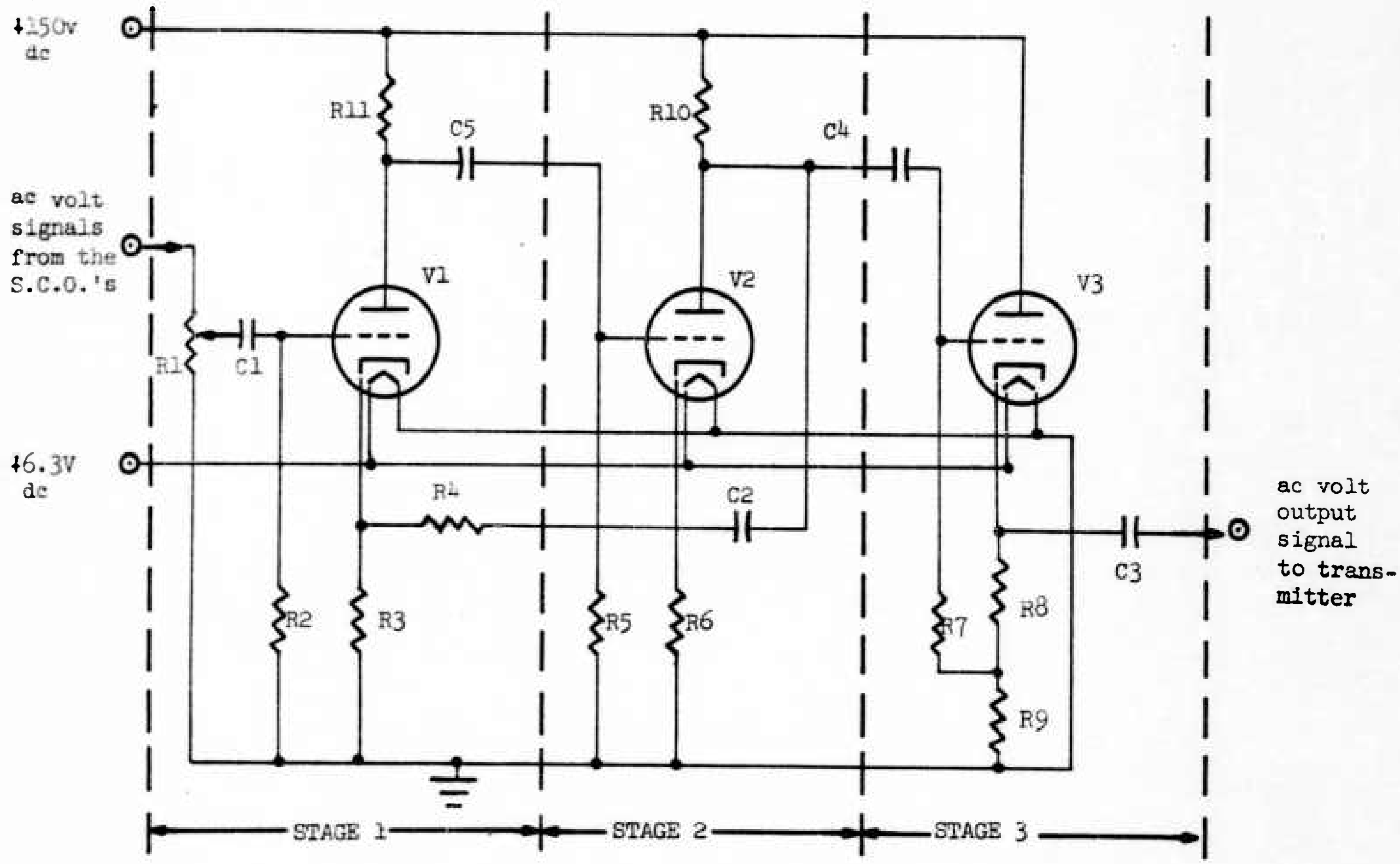


FIGURE 12 MULTIVIBRATOR OUTPUT (14.5 Kc SUBCARRIER OSCILLATOR)



Note - Refer to Table No. 5 for Element Values

FIGURE 13 SCHEMATIC DIAGRAM FOR THE MIXER AMPLIFIER, VECTOR MODEL A-80

TABLE 5
POST IRRADIATION EVALUATION FOR COMPONENTS OF THE MIXER - AMPLIFIER
VECTOR MODEL
(REFERENCE SCHEMATIC DIAGRAM, FIGURE 13)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Pot	R1	10K ohm	Ohmite	AS	Molded composition	Insignificant resistance change
Resistor[1]	R2	1M ohm .25w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R3	1K ohm .5w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R4	27K ohm .5w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R5	1M ohm .25w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R6	1K ohm .25w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R7	1M ohm .25w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R8	300 ohm .25w	IRC	RN20X	Deposited carbon	Insignificant resistance change

TABLE 5 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Resistor[1]	R9	100 ohm .5w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R10	51K ohm 1w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Resistor[1]	R11	51K ohm 1w	IRC	RN20X	Deposited carbon	Insignificant resistance change
Capacitor[3]	C1	0.33 mfd	Goodall		Metalized mylar (tublar)	Capacitor end caps were swollen, however none of the capacitors failed.
Capacitor[3]	C2	0.33 mfd	Goodall		Metalized mylar (tublar)	
Capacitor[3]	C3	0.33 mfd	Goodall G		Metalized mylar (tublar)	
Capacitor[3]	C4	0.22 mfd	Goodall		Metalized mylar (tublar)	
Capacitor[3]	C5	0.047 mfd	Goodall		Metalized mylar (tublar)	
Tube, Electron	V1		GE	6111 5 Star	Glass envelope sub-miniature	Lack of signal across the tube indicated that the grid to plate transconductance was zero. (Note 2.)
Tube, Electron	V2		GE	6111 5 Star	Glass envelope sub-miniature	Insignificant change

TABLE 5 (CONTINUED)

ELEMENT	CODE VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Tube, Electron	V3	GE	6111 5 Star	Glass envelope sub-miniature	Insignificant change

NOTES

1. All resistors have ±1% tolerance.

2. It was not discernible whether reduction of tube transconductance to zero was attributable to nuclear or non-nuclear causes.

3. All capacitors are rated at 200 volts.

clearly shown in the telemetering block diagram (Fig. 1). A schematic diagram for the Vector Type A-80 mixer amplifier is presented in Figure 13 with electronic element identification numbers which are used as an index reference to Table 5. For each coded element appearing in Figure 13, Table 5 gives pertinent information, including element, value, vendor, type, description and post irradiation evaluation.

A nuclear radiation effects evaluation of the mixer amplifier was performed to assess what modifications were feasible to increase its nuclear radiation compatibility. Materials and component replacement modifications which were accomplished are detailed in Table 6.

TABLE 6

MIXER AMPLIFIER MODIFICATIONS

Electronic Element	Original Element		Replacement Element	
	Description	Nuclear Functional Threshold	Description	Nuclear Functional Threshold
Electrical Wire Insulation	Teflon	1.0×10^{7} ergs/gm-(C)	Polyvinylchloride with Fiberglass Tubing	2.0×10^{10} ergs/gm-(C)
Capacitors	Paper, 200 volts Aerovox .5 mfd .25 mfd .033 mfd	1.1×10^{8}	Mylar, 200 volts Goodall .5 mfd .25 mfd .033 mfd	1.2×10^{10} ergs/gm-(C)
Resistors	Carbon Composition 200 volts. I. R. C. IM ohm, .25 w IK ohm, .5 w 10K ohm, 1 w	2.0×10^{10}	Deposited Carbon 200 Volts I.R.C. IM ohm, .25 w IK ohm, .5 w 10K ohm, 1 w	1×10^{11} ergs/gm-(C)
Tube, Electron	Glass Sub-miniature 6111	1.0×10^{16} n/cm^2	Glass envelope Sub-miniature, 6111, Five Star	5.0×10^{16} n/cm^2

As in the case of the SCO's most of the hookup wire was Teflon insulated and had to be replaced. Here too the packing density was greatly increased, thus introducing problems of reducing heat dissipation. There was no apparent heating during the test, however.

Other replacements were: mylar insulated capacitors were substituted for paper insulated capacitors, carbon composition resistors were replaced with deposited carbon resistors and 6111 glass envelope subminiature electron tubes were replaced with G.E. Five Star 6111 glass envelope subminiature electron tubes. Electrical characteristics were not changed by these modifications as evidenced by pre-irradiation instrumentation check-out and prolonged stable operation.

Each stage of the mixer amplifier was instrumented to facilitate failure locations during the irradiation, reference Figure 1. A complete dependence on SCO output signal for an input voltage signal, sacrificed mixer amplifier operation during most of the irradiation. SCO multivibrator stage failures after 2.9 hours of reactor operation terminated operation of the mixer-amplifier. At that time the mixer had been subjected to a nuclear radiation exposure of 1.3×10^9 ergs/gm-(C) and 4.0×10^{14} n_f/cm^2, reference Figure 11. Output voltage from each stage followed the fluctuations of the SCO outputs to failure. There was no indication of any nuclear radiation induced changes in electronic elements at that time.

Normal operation of the mixer amplifier was restored by replacing the Five Star 6111 subminiature glass envelope electron tube V1 in stage one, Figure 13, during the post irradiation test. Tube pins were broken off during disassembly; however, lack of signal across the tube indicated grid to plate transconductance was zero. It was not discernible whether this affect was attributable to nuclear or non-nuclear causes or a combination of both. All of the capacitors had a swollen appearance marked with small bubble voids. This appearance can be attributed to gassing of the mylar and encapsulating materials as a result of gamma energy deposition. This degradation apparently did not change the electrical properties of the capacitor enough to result in a gross change in electrical properties. No attempt was made to isolate each electronic element and assess changes in electrical properties.

2.5 General Transmitter Operation

Telemetering transmitter operating parameters are covered by Inter-Range Instrumentation Group (IRIG) telemetry standards contained in IRIG Document No. 106-60. Pertinent telemetering transmitter standards are:

a. frequency band 216 to 260 Mcs

b. maximum rf carrier modulation deviation of plus or minus 125 Kcs

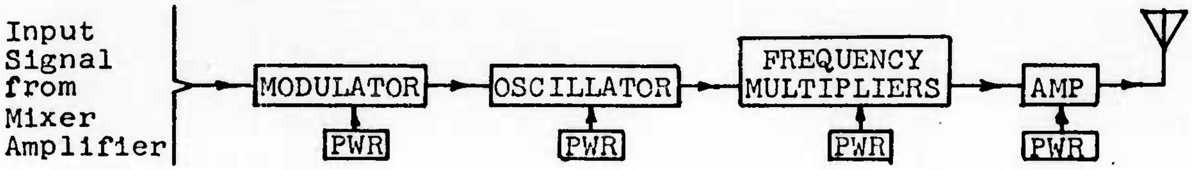
c. frequency stability - carrier stable within $\pm$ .01% of assigned carrier frequency

d. one hundred (100) watts maximum power, with actual use as small as permissible

A typical telemetering transmitter block diagram appears in Figure 14 below:

FIGURE 14

TELEMETERING TRANSMITTER BLOCK DIAGRAM



This diagram typifies an angular modulation transmitter in which the intelligence is impressed along the time axis of the carrier current in such a manner that the instantaneous carrier frequency is directly proportional to the modulation signal amplitude. This process is utilized in the Telechrome transmitter as modified for this test. For the Bendix transmitter, however, the modulation intelligence is impressed along the time axis, but is applied at a stage following the frequency controlling element; thus the result is phase modulation. This implies that the apparent f.m. manifested by the existence of carrier frequency deviation is an indirect effect of phase departures created by the modulation wave form. In a perfectly linear uncompensated system this indirect deviation of frequency is the time deviation of the phase departure and is equivalent to the rate of change (amplitude per unit time) of the modulation signal. Both transmitters do incorporate circuit elements which provide a degree of modulation amplitude, with frequency compensation, which results in a pseudo-direct f.m. at modulation signal frequencies above about 50 cps.

It becomes increasingly difficult to maintain oscillator frequency stability at higher frequencies; therefore, when working at high transmitting frequencies it is desirable to operate the oscillator at a low frequency and follow it with a series of frequency multipliers, as required, to produce the output transmission frequency. A frequency multiplier is an amplifier that delivers an output at a multiple of the exciting frequency. From the viewpoint of any particular stage in the transmitter, the preceeding stage is the driver.

Generally, frequency multipliers should not be used to feed the antenna system directly, but should feed a straight power amplifier which in turn feeds the antenna system as shown in Figure 14 above.

Good frequency stability is most easily obtained through the use of a quartz crystal controlled oscillator. The frequency depends

almost entirely on the dimensions of the crystal (primarily its thickness); other circuit values have comparatively negligible effect. However, the power obtainable is limited by the Δt the crystal will stand without fracturing. Amount of frequency drift as a result of heating is a property of the quartz crystal cut. AT or BT type of quartz crystal cuts is used for frequencies and temperatures of interest here.

The effectiveness of f.m. and p.m. for communication purposes depends almost entirely on the receiving methods. If the receiver will respond to frequency and phase changes but is insensitive to amplitude changes, it will discriminate against most forms of noise. Special methods are required to accomplish the result. Modulation methods for f.m. and p.m. are simple and require little power and therefore are desirable techniques for lightweight portable telemetering systems.

2.5.1 Telechrome Model 1472-A2 FM/FM Subminiature Telemetering Transmitter

This transmitter has been used extensively in flight test programs for military aircraft and has a minimum two watt power rating in the 215 to 235 megacycle band. The circuits include a quartz crystal controlled oscillator operating at one-sixth of carrier frequency output signal, 230.4 Mcs, driven by a frequency modulator circuit. The unit is designed to accept modulation frequencies of 100 cps to 80 Kcs, and over this range the deviation sensitivity is 2.75 volts peak to peak for ± 75 Kc RF deviation, and the modulation frequency response is flat to within ±3 db. Cooling is achieved by a heat sink over the range -55°C to +100°C, and the unit has other rugged qualities to suit military operational environments.

The Telechrome telemetering transmitter is made up of the following stages:

(a) Modulator, FM

(b) Crystal controlled oscillator combined with a frequency amplifier (tripler)

(c) Frequency amplifier (doubler)

(d) Amplifier

Its function in the telemetering system is illustrated in Figure 1. The oscillator in Figure 15 combines the functions of oscillator and frequency multiplier in a single pentode. The screen of the pentode is used as the plate in the oscillator. Complete specifications for the transmitter are contained in Appendix B3.

A nuclear radiation effects evaluation of the Telechrome transmitter was performed to assess what modifications were feasible to extend its operational life in a nuclear radiation environment. Materials and components replacement modification are presented in Table 7.

TABLE 7

NUCLEAR RADIATION EFFECTS MODIFICATIONS OF THE TELECHROME TRANSMITTER

	Original Element		Replacement Element	
Electronic Element	Material Description	Nuclear Functional Threshold	Material Description	Nuclear Functional Threshold
Resistors	Carbon composition .5w Allen Bradley	2.0×10^{10} ergs/gm-(C)	Deposited carbon .5w IRC	1.0×10^{11} ergs/gm-(C)
Tube, Electron	Glass envelope subminiature Raytheon 5703/5703 WA	1.0×10^{15} n_f/cm^2	Glass envelope subminiature Sylvania 5703/5703WA	1.0×10^{16} n_f/cm^2
Electrical wire insulation	Teflon	1.0×10^{7} ergs/gm-(C)	Polyvinyl-chloride with fiberglass sleeving	2.0×10^{10} ergs/gm-(C)
Diode	Silicon, Raytheon in 301	1.0×10^{14} n_f/cm^2	Redesigned to eliminate diode (see text)	
Connector female coax	Teflon insulation, Amphenol UG-1094/U	1.7×10^{7} ergs/gm-(C)	Polystyrene insulation, Amphenol UG-657/U	6.0×10^{10} ergs/gm-(C)

Essentially the modifications are the same as those for the SCO's and mixer amplifier with the exception of partial redesign of the modulator oscillator circuits to eliminate a IN301 silicon diode. The modified Telechrome transmitter schematic diagram is shown in Figure 15. For comparison, that portion of the circuit which was affected by circuit redesign is shown in Figure 16. Comparison of Figure 15 and 16 reveals that the major circuit modification was to alter the quartz crystal driving circuit from the modulator electron tube plate. Modification was accomplished without changing the output parameters of the transmitter.

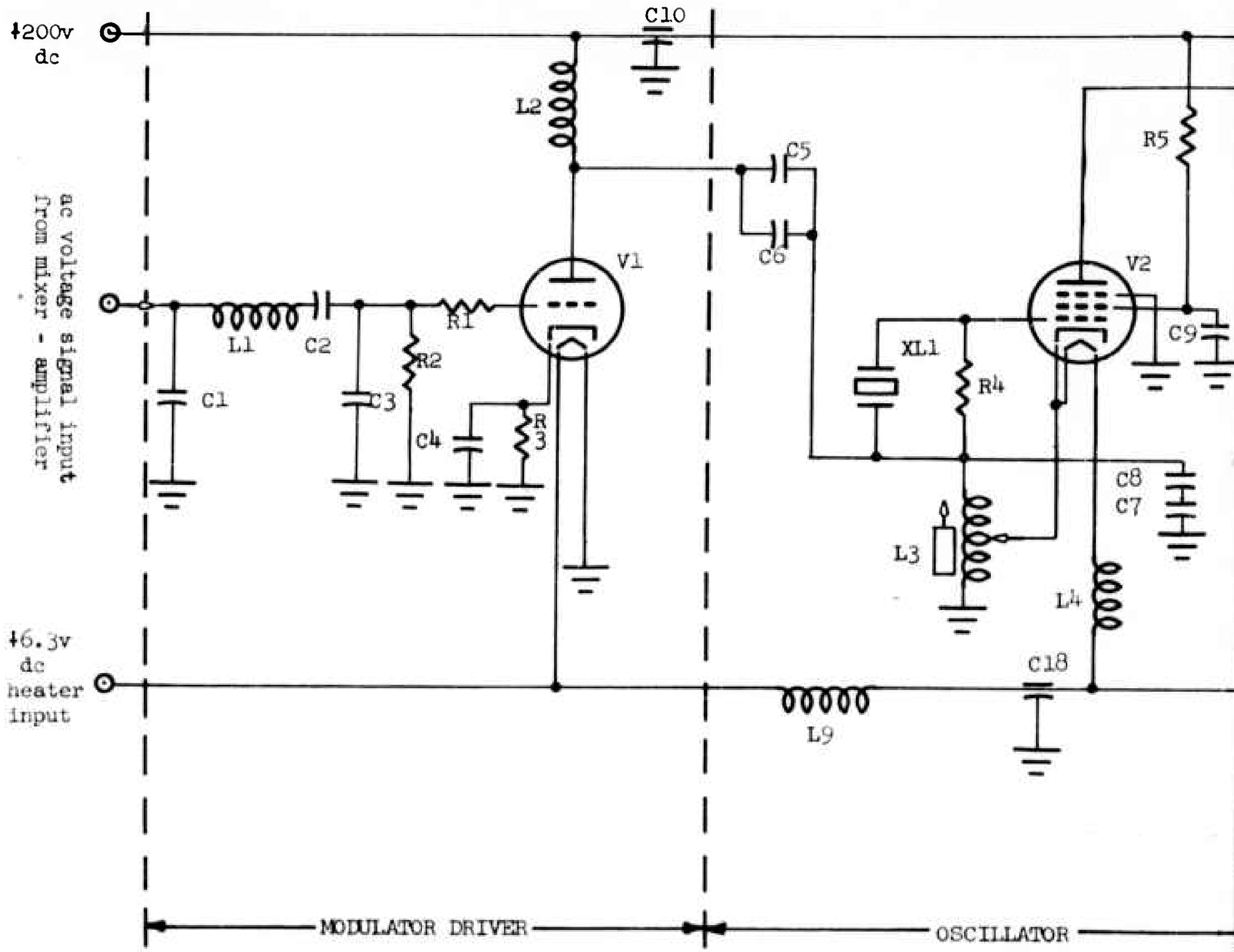
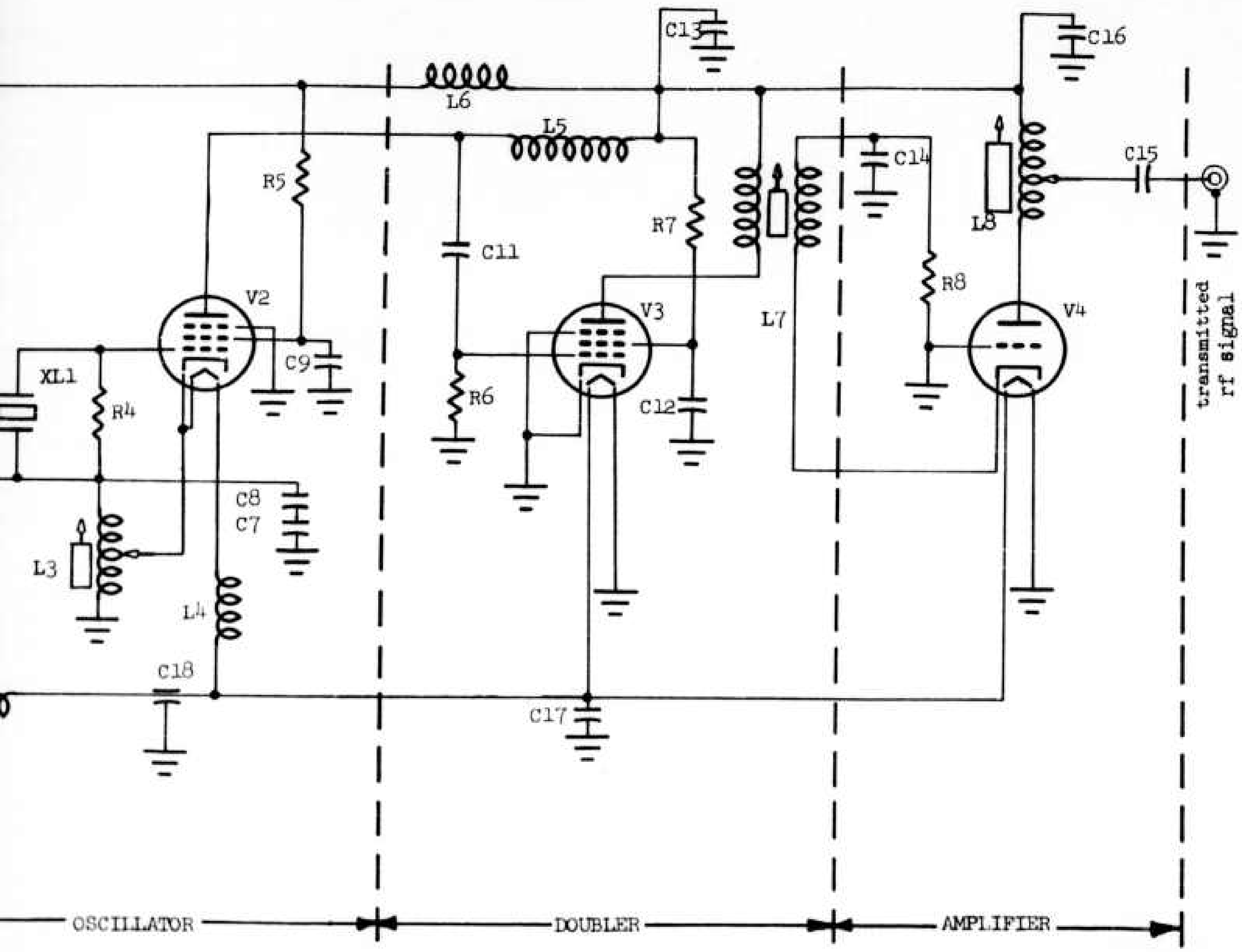


FIGURE 15 SCHEMATIC DIAGRAM FOR THE TELE
(REFER TO TABLE



2

ATIC DIAGRAM FOR THE TELECHROME MODEL 1472A FM/FM TELEMETERING TRANSMITTER
(REFER TO TABLE 8 FOR ELEMENT VALUES)

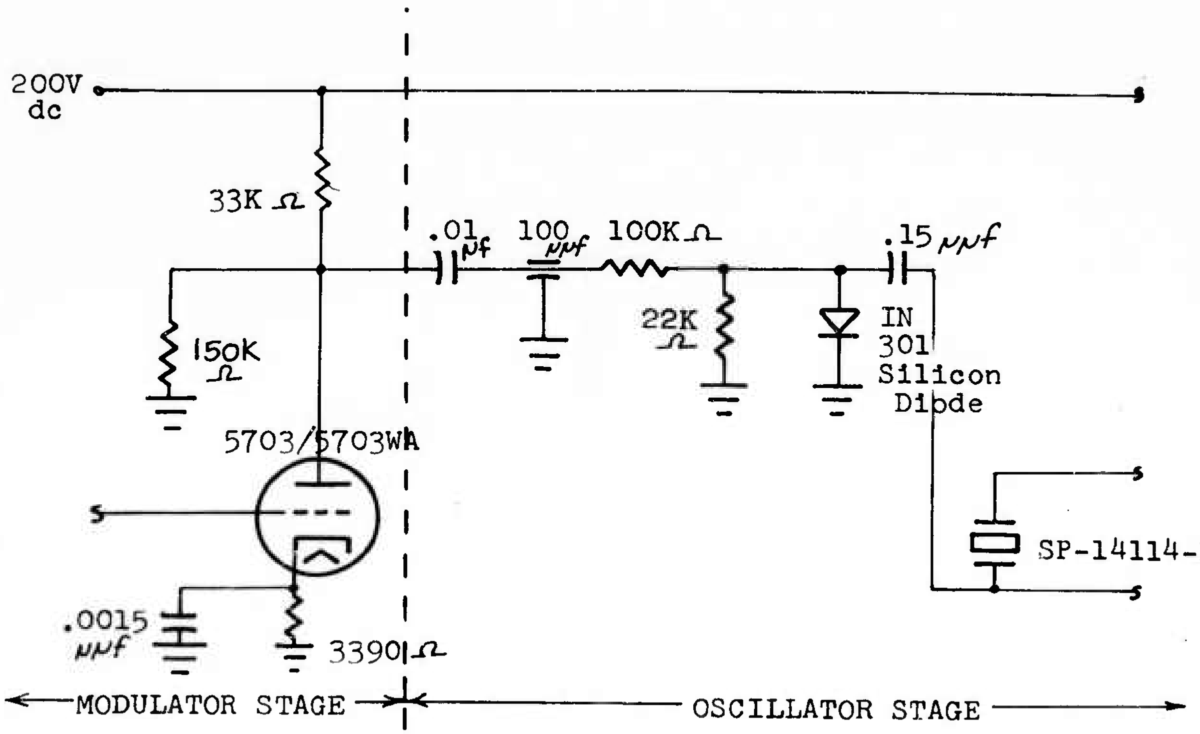


FIGURE 16 PART OF TELECHROME TRANSMITTER CIRCUIT BEFORE REDESIGN

Electronic element identification numbers which appear on the schematic diagram, Figure 15, are index references to Table 8. For each coded element appearing in Figure 15, Table 8 gives pertinent information including element, value, vendor, type, description, and brief post irradiation evaluation.

Before the transmitter was installed on the pallet, a complete checkout was made which confirmed normal operation. Next the transmitter was installed on the pallet in the telemetering system, see Figure 1, where prolonged steady state operation was achieved both in the laboratory and in position next to the reactor. Power output (watts), carrier frequency deviation (Kc), and modulation frequency deviation (Kc) were the parameters monitored before and during the irradiation test. These parameters were monitored using a cable link rather than antenna link because of the complex experimental environment.

Carrier frequency deviation and output power is plotted against reactor operating time in Figure 17. Although carrier frequency is not perfectly stable, it is well within $\pm$ .01% of 229.9 Mc prior to reactor start up. After start up, and until failure, carrier frequency deviation decreased at a high rate. After 1.6 hours, at 0.5 Mw reactor power, carrier frequency drift exceeded -.01% of

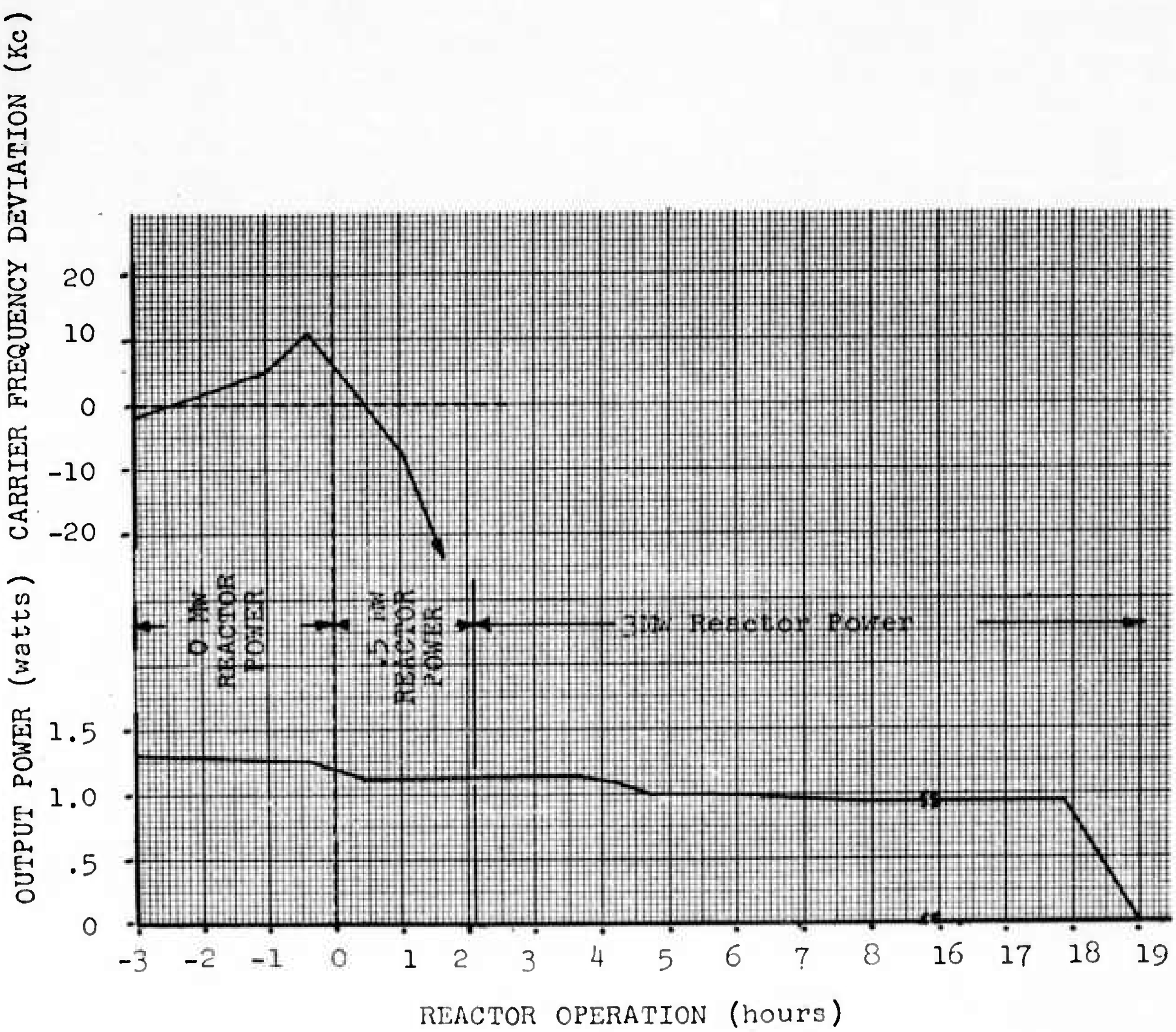


FIGURE 17 FM/FM 230 Mc TELEMETERING TRANSMITTER OUTPUT

TABLE 8

POST IRRADIATION EVALUATION FOR COMPONENTS OF THE TELECHROME 1472A FM/FM TELEMETERING TRANSMITTER (REFERENCE SCHEMATIC DIAGRAM, FIGURE 15)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Resistor[2]	R1	100 ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R2	2.2M ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R3	235 ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R4	39K ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R5	15K ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R6	330K ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R7	15K ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R8	150 ohm	IRC	RN20X	Deposited carbon	Note 1
Resistor[2]	R9	220 ohm	IRC	RN20X	Deposited carbon	Note 1
Capacitor	C1	47 mmfd 600v	Centra-lab	TCN-47	Ceramic	Note 1

TABLE 8 (Continued)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Capacitor	C2	.01 mfd 200v	Goodall	615G	Vinyl	Note 1
Capacitor	C3	100 mmfd 500v	Sprague	507C 20A	Ceramic	Note 1
Capacitor	C4	430 mmfd 500v	El-Menco	CM-15	Mica	Note 1
Capacitor	C5	1.5 mmfd 600v	Centra-lab	TCZ-1.5	Ceramic	Note 1
Capacitor	C6	1.5 mmfd 600v	Centra-lab	TCZ-1.5	Ceramic	Note 1
Capacitor	C7	3.3 mmfd 600v	Erie	N750 A3R3	Ceramic	Note 1
Capacitor	C8	22 mmfd 600v	Centra-lab	TCZ-22	Ceramic	Note 1
Capacitor	C9	47 mmfd 600v	Centra-lab	TCN-47	Ceramic	Note 1
Capacitor	C10	1K mmfd 600v	Centra-lab	MFT-1000	Ceramic	Note 1

TABLE 8 (Continued)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Capacitor	C11	22 mmfd 600v	Centra-lab	TCZ-22	Ceramic	Note 1
Capacitor	C12	1K mmfd 600v	Sprague	507C	Ceramic	Note 1
Capacitor	C13	1K mmfd 600v	Sprague	507C	Ceramic	Note 1
Capacitor	C14	1K mmfd 600v	Sprague	507C	Ceramic	Note 1
Capacitor	C15	47 mmfd 600v	Centra-lab	TCN-47	Ceramic	Note 1
Capacitor	C16	1K mmfd 600v	Sprague	507C	Ceramic	Note 1
Capacitor	C17	1K mmfd 600v	Sprague	507C	Ceramic	Note 1
Capacitor	C18	1K mmfd 600v	Centra-lab	MFT-1000	Ceramic	Note 1
Choke, RF	L1	6.8 mh	Jeffers	10102-28		Functioning

TABLE 8 (Continued)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Coil	L2	0.6 mh				Functioning
Coil	L3	Adj.	CTC	CD-14731		Functioning
Coil	L4	Adj.	CTC	CD-14731		Functioning
Choke, RF	L5	6.8 mh	Jeffers	10102-28		Functioning
Choke, RF	L6	.68 mh	Jeffers	10102-28		Functioning
Coil	L7	Adj.	CTC	CD-14731		Functioning
Coil	L8	Adj.	CTC	CD-14731		Functioning
Choke, RF	L9	.68 mh	Jeffers	10100-28		Functioning
Crystal (Quartz)	XL1	38.4233 Mc	Hunt	SP-14114-2-2	1/6 of transmitter output freq.	Freq. deviation exceeded - .01% at a dose of 6.0×10^{15} n/cm^2 (E >1.0 Mev) & 2.1×10^{10} $\frac{ergs}{gm}$ (C) due to agglomeration of Ag electrodes.
Tube, Electron	V1		Sylvania	5703/ 5703 WA	Glass envelope sub-miniature	
Tube, Electron	V2		Sylvania	5702/ 5702WA	Glass envelope sub-miniature	

TABLE 8 (Continued)

ELEMENT	CODE VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Tube, Electron	V3	Sylvania	5702/ 5702 WA	Glass envelope sub-miniature	
Tube, Electron	V4	Sylvania	5703/ 5703 WA	Glass envelope sub-miniature	

NOTES

1. Transmitter failure resulted from the combined effects of:

   a. Small changes in passive elements.

   b. Changes of resonant freq. of amplifier stages.

   c. Electron Tube characteristic changes.

   d. Change in freq. of crystal controlled oscillator due to quartz crystal electrode deterioration.

2. All deposited carbon resistors are 0.5 watt $\pm 1\%$.

the assigned value. At that time the Telechrome transmitter had a nuclear radiation exposure of 3.7×10^8 ergs/gm-(C) and 1.0×10^{14} n_f/cm^2 (Ref. Fig. 18). After 3.9 hours of reactor operation, carrier frequency was 100 Kc low, and it was decided not to continue to monitor it any longer.

Telechrome power output was stable at 1.3 watts just prior to reactor start up with no significant changes for 4 hours, when power was degraded to 0.9 watts. It remained perfectly stable at this value until failure occurred after 19 hours and a nuclear radiation exposure of 2.0×10^{10} ergs/gm-(C) and 6.0×10^{15} n_f/cm^2. Static irradiation continued until a total of 80.73 hours of reactor operation were accumulated, which was equivalent to a nuclear radiation exposure of 1.1×10^{11} ergs/gm-(C) and 3.0×10^{16} n_f/cm^2.

A post irradiation evaluation of the Telechrome transmitter was conducted to determine the reasons for the failure in carrier frequency and output power. Output power was restored to the pre-irradiation value of 1.3 watts by adjusting L3, L7, and L8 inductor tuners, Figure 15. It was concluded that nuclear radiation induced small changes in resistors, capacitors, and electron tubes which caused power failure. This conclusion is based upon the fact that the type of capacitors, resistors and electron tubes listed in Table 8 do exhibit characteristic property degradation in the nuclear radiation exposure region where transmitter power failure occurred. It was beyond the scope of this test to examine in detail each electronic element.

All attempts to restore normal carrier frequency in the oscillator circuit failed. The quartz crystal used to control the oscillator circuit, Figure 15, was designed to operate at one-sixth the output carrier frequency of 230.4 Mc or 38.4233 Mc. A 231.573 Mc carrier frequency signal was detected at 1.3 watts output power. This represents a $+$ 0.45% change in carrier frequency which is 0.44% larger than IRIG specifications allow. An attempt to check the resonant frequency of the Telechrome quartz crystal SP-14114-1-2, which was specified as 90 Kc above design frequency of 38.5133 Mc, was unsuccessful, for the crystal did not exhibit any resonant conditions. Since environmental overheating was not believed to be a factor in the test, only normal random failure and nuclear radiation damage could account for this behavior. Subsequent disassembly of the HC-6/U quartz crystal holder was accomplished to evaluate the physical condition of the quartz crystal, plated electrodes, and mounting. The unit was a silver electrode, unpolished round BT cut quartz plate, wire-mounted in a metal holder, (HC-6/U), with a glass base utilizing a Teflon liner. It was established that the wire holders were securely attached to the quartz plate. The Teflon seal between the glass base and metal container was completely destroyed by nuclear radiation; however, it was not possible to prove that humid air had diluted the dry nitrogen in the container. MIL-C-3098C requires that HC-6/U crystal unit with glass bases be filled with dry nitrogen at atmospheric pressure and sealed. A continuity check between the silver

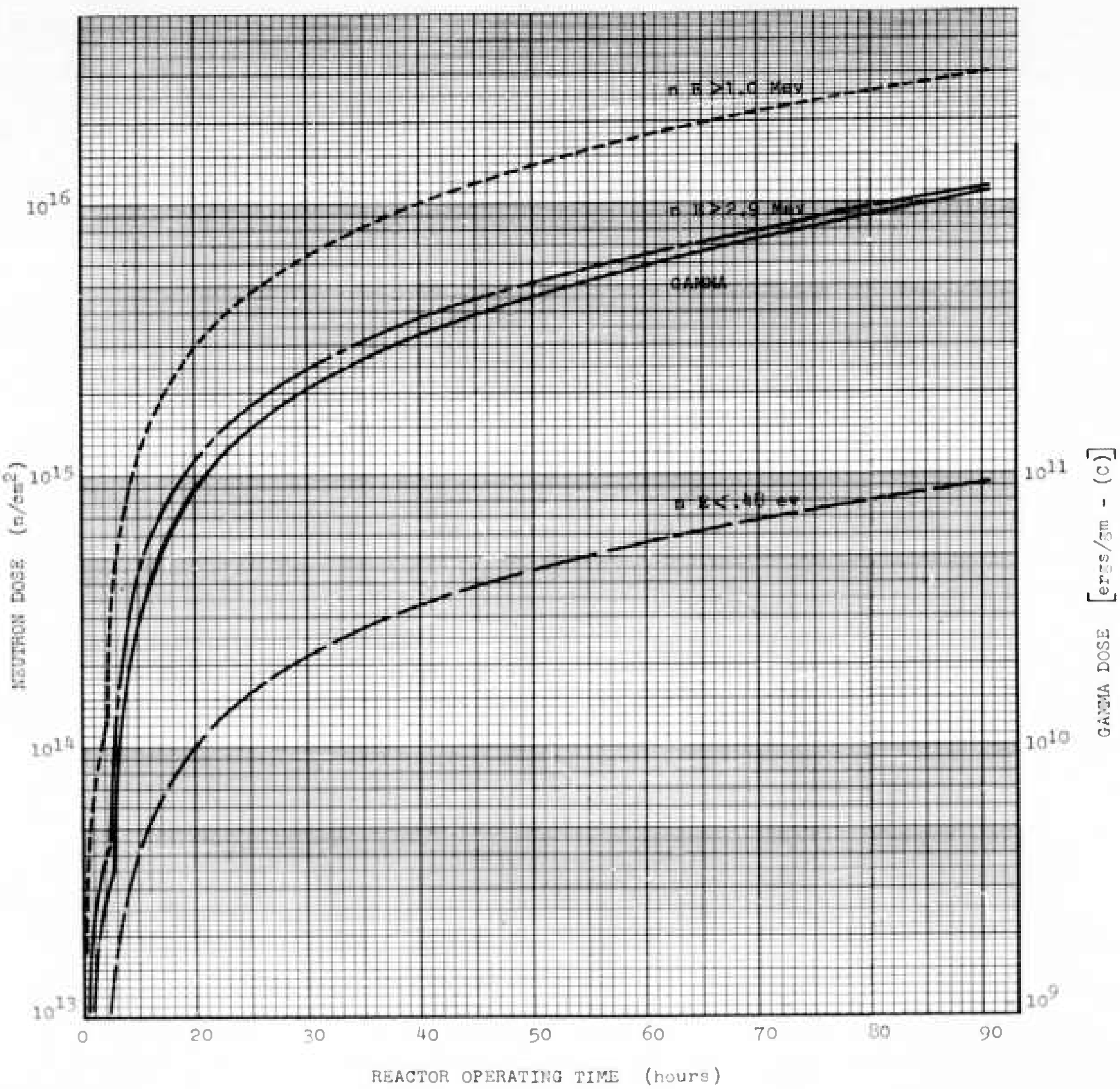


FIGURE 18 NUCLEAR RADIATION EXPOSURE FOR THE 230 Mc FM/FM TRANSMITTER

plated electrode at the metal holder and the middle of the crystal indicated an open circuit. This condition existed for electrodes on both sides of the quartz crystal. Comparison with an unirradiated quartz crystal of the same type revealed that the silver plating on the irradiated sample was very much thinner and in spots almost gone as compared to the unirradiated quartz crystal. This contrast is illustrated by the photomicrograph, Figures 19 and 20, which are 150X magnifications of the silvered electrode area of the irradiated and non-irradiated quartz crystals. As discussed in Reference 1, this vanishing of the silver was actually an agglomeration; that is, the silver film actually clustered into small balls. This explains the translucent appearance of the electrodes, loss of conductivity, and loss of characteristic resonant frequency. Sufficient nuclear radiation environment testing of quartz crystals has been performed to establish the fact that there is a definite relationship between orientation of quartz crystal cut and nuclear radiation induced failure rate, Reference 2 and 3. Bottom and Nowicki (Ref. 2) found that AT cut quartz crystal plates irradiated to saturation with X-rays were little affected. BT cut quartz crystal plates on the other hand were appreciably affected by the same radiation. Confirmation of the BT results was obtained by Frondel (Ref. 3 and 4) and Johnson and Pease.

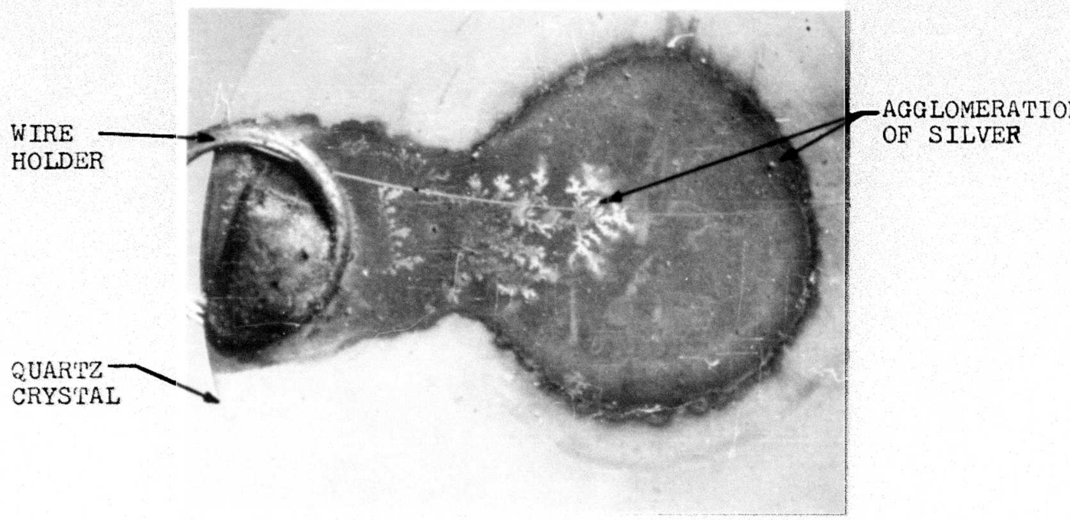
It was concluded that the Telechrome transmitter failure, after 1.6 hours of nuclear radiation exposure to 3.7×10^{8} ergs/gm-(C) and 1.0×10^{14} n_f/cm^2, due to quartz crystal frequency shift was caused by nuclear radiation induced material degradation.

2.5.2 Bendix Model TXV-13 PM/FM Telemetering Transmitter

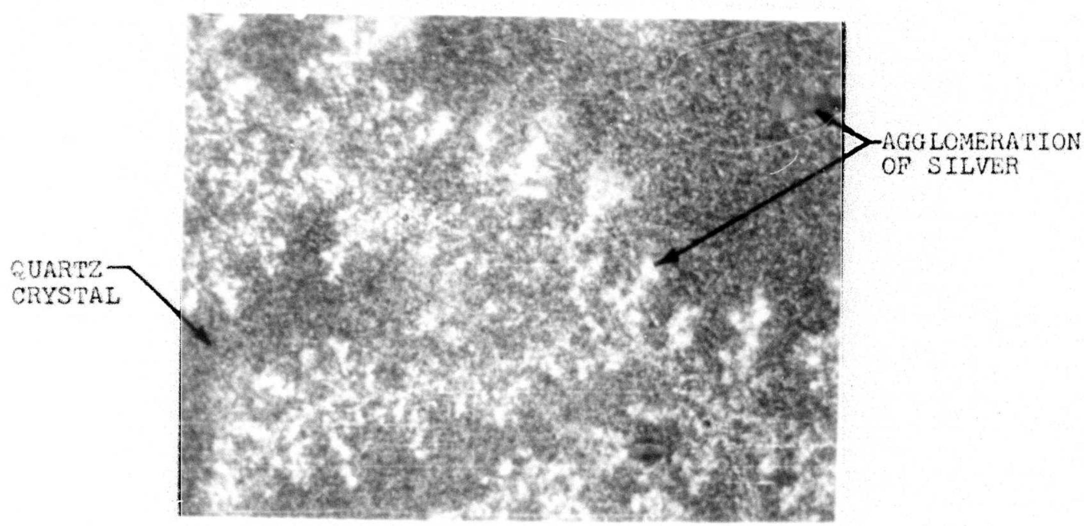
This transmitter has been used extensively in flight test programs for military aircraft. It has a minimum one point eight watt power rating in the 215 to 235 megacycle band, and includes a quartz crystal controlled oscillator operating at one-twenty-fourth of carrier frequency output signal, 230.4 Mcs, driven by a phase modulated circuit. The modulator input circuit includes an integrating circuit to compensate for multiplication of source harmonic distortion resulting from differentiating action characteristic of uncompensated phase modulation. The integrating circuit is effective down to a modulating frequency of 5 Kc which provides proper balance between adequate deviation sensitivity at higher modulating frequencies and low distortion. Six subminiature tubes are employed in the transmitter functioning as an oscillator, reactance tube modulator, quadrupler, tripler, doubler and final amplifier to produce a nominal 2.0 watt frequency deviated signal. Cooling is achieved by a heat sink over the range -55°C to + 100°C, and the unit features a high degree of stability and reliability incorporated in a subminiature size to suit military operational environments.

The Bendix TXV-13 PM/FM transmitter is made up of the following stages:

(a) Modulator, PM



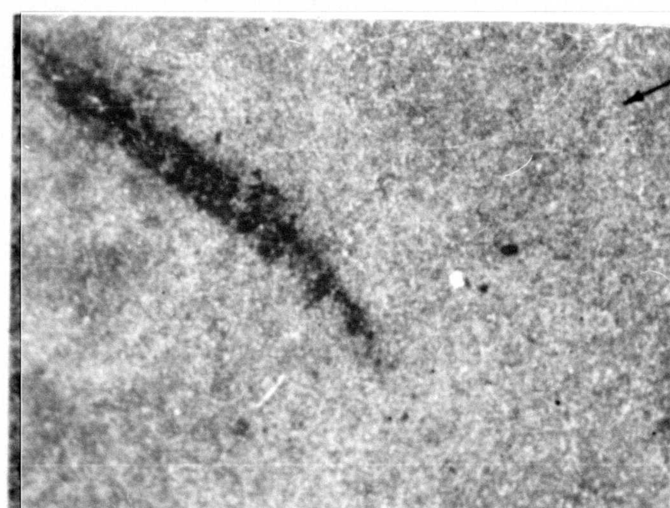
COMPLETE VIEW OF SILVER ELECTRODE



ENLARGED VIEW OF ELECTRODE

FIGURE 19 IRRADIATED TELECHROME QUARTZ CRYSTAL # SP-14114-1-2
(HC-6/U)

COMPLETE VIEW OF SILVER ELECTRODE



ENLARGED VIEW OF ELECTRODE

FIGURE 20 UNIRRADIATED TELECHROME QUARTZ CRYSTAL # SP-14114-1-2 (HC-6/U)

(b) Crystal controlled oscillator

(c) Frequency amplifier, quadrupler

(d) Frequency amplifier, tripler

(e) Frequency amplifier, doubler

(f) R. F. Amplifier

Its function in the overall telemetering system is illustrated in Figure 1.

If the phase of the current in the oscillator circuit is changed there is an instantaneous frequency change during the time that the phase is being shifted. The amount of frequency change or deviation depends on how rapidly the phase shift is accomplished. It is also dependent upon the total amount of the phase shift. Amount of phase shift is proportional to the instantaneous amplitude of the modulating signal. The rapidity of the phase shift is directly proportional to the frequency of the modulating signal. Consequently, the frequency deviation in p.m. is proportional to the frequency and amplitude of the modulating signal. The latter represents the outstanding difference between p.m. and f.m., since in f.m. the frequency deviation is proportional only to the amplitude of the modulating signal. Complete specifications for the transmitter are contained in Appendix B4.

A nuclear radiation effects evaluation of the Bendix transmitter was performed to assess what modifications were feasible to extend its operational life in a nuclear radiation environment. Materials and components replacement modification are presented in Table 9.

TABLE 9

NUCLEAR RADIATION EFFECTS MODIFICATION OF THE BENDIX TRANSMITTER

Electronic Element	Original Element		Replacement Element	
	Material Description	Nuclear Functional Threshold	Material Description	Nuclear Functional Threshold
Electrical wire insulation	Teflon	1.0×10^{7} ergs/gm-(C)	Polyvinyl-chloride with fiberglass sleeving	2.0×10^{10} ergs/gm-(C)
Crystal Holder	Teflon	1.0×10^{7} ergs/gm-(C)	Ceramic	5×10^{11} nf/cm^2

TABLE 9 (Continued)

Electronic Element	Original Element		Replacement Element	
	Material Description	Nuclear Functional Threshold	Material Description	Nuclear Functional Threshold
Capacitor	Paper 400 volts Sprague	1.1×10^{8} ergs/gm-(C)	Mylar 400 volts Goodall	1.2×10^{10} ergs/gm-(C)
Resistors	Carbon composition .5w, 500 volts Allen Bradley	2.0×10^{10} ergs/gm-(C)	Deposited carbon .5w,500 volts IRC	1.1×10^{11} ergs/gm-(C)

Replacement of the Teflon crystal holder with a ceramic type was the only modification which was different from S C O and Mixer modification. The modified Bendix transmitter schematic diagram is shown in Figure 21. Electronic element identification numbers which appear on the schematic diagram, Figure 21, are index references to Table 10. For each coded element appearing in Figure 21, Table 10 gives pertinent information, including element, value, vendor, type, description and brief post irradiation evaluation.

After modification an attempt was made to adjust the Bendix transmitter for normal operation. Nominal R. F. output power of 2.0 watts was never attained despite exhaustive testing. A 1.7 watt R. F. power output was achieved at one time but it was highly unstable with an uncontrollable negative drift. Since the transmitter functioned correctly prior to modification, apparently a combination of incompatible electronic variables was introduced. Time available for laboratory checkout of the transmitter before the nuclear irradiation prohibited a prolonged circuit analysis; hence, stable output R. F. power was never achieved. Small changes in oscillator circuit parameters have little effect on quartz crystal control of oscillator frequency; therefore, electronic circuit errors introduced by modification did not affect carrier frequency stability.

Even though the transmitter power problem had not been solved, it was decided to include it in the nuclear radiation test per original plans. Pre-irradiation base line data was taken with transmitter in position adjacent to the reactor. By that time R. F. output power had decreased to 0.75 watts but carrier frequency was still stable (Ref. Fig. 22). Output power continued to drop after reactor start up and went to zero after 2.4 hours of reactor operation, which was equivalent to a nuclear radiation exposure of 8.0×10^{8} ergs/gm-(C) and 3×10^{14} n_f/cm^2 (Ref. Fig. 23). At that time the carrier frequency was stable, which indicated that the oscillator stage and frequency multiplier stages (Ref. Fig. 21) were still functioning. Bendix transmitter B+ kept on through the remainder of the irradiation.

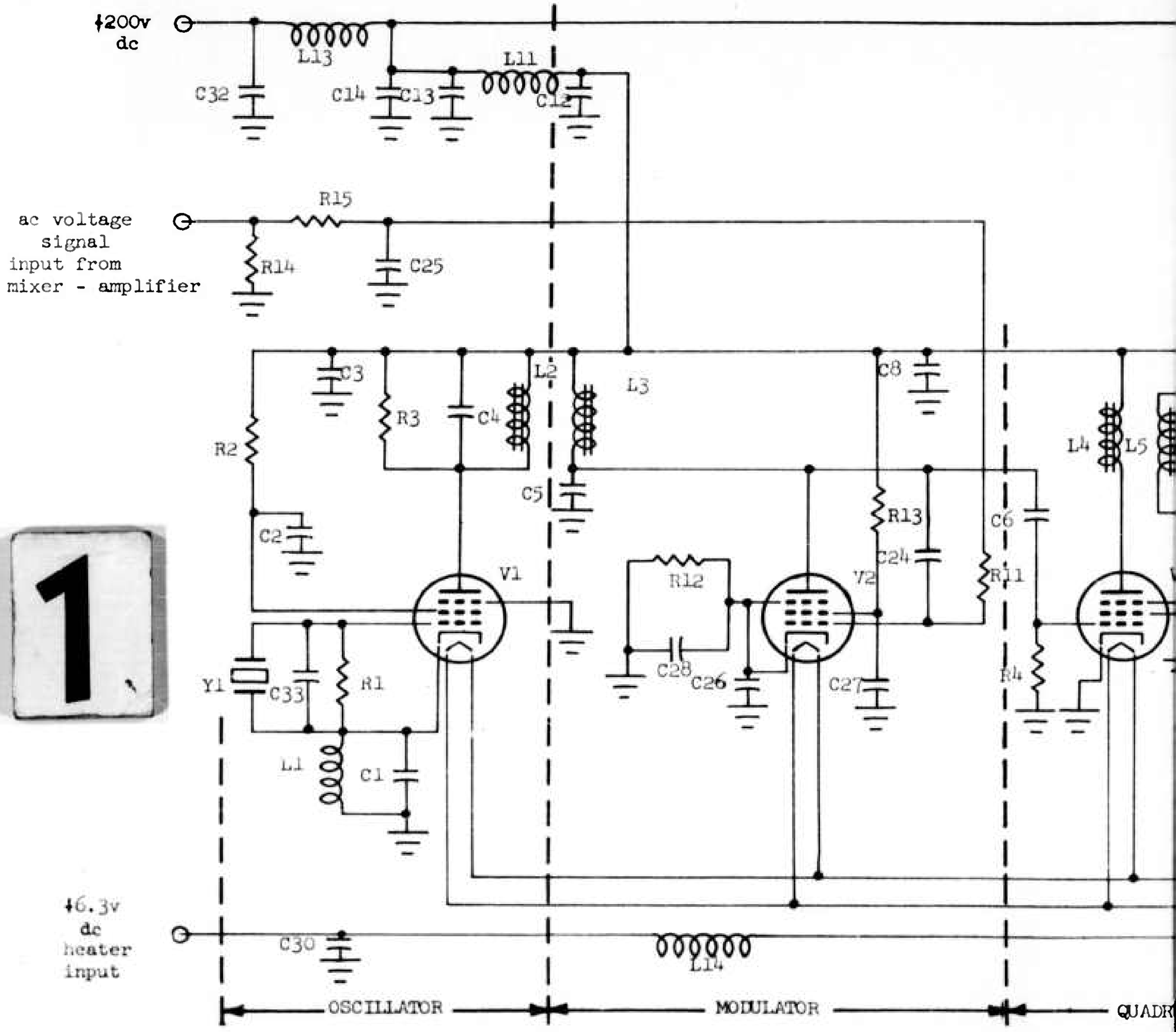
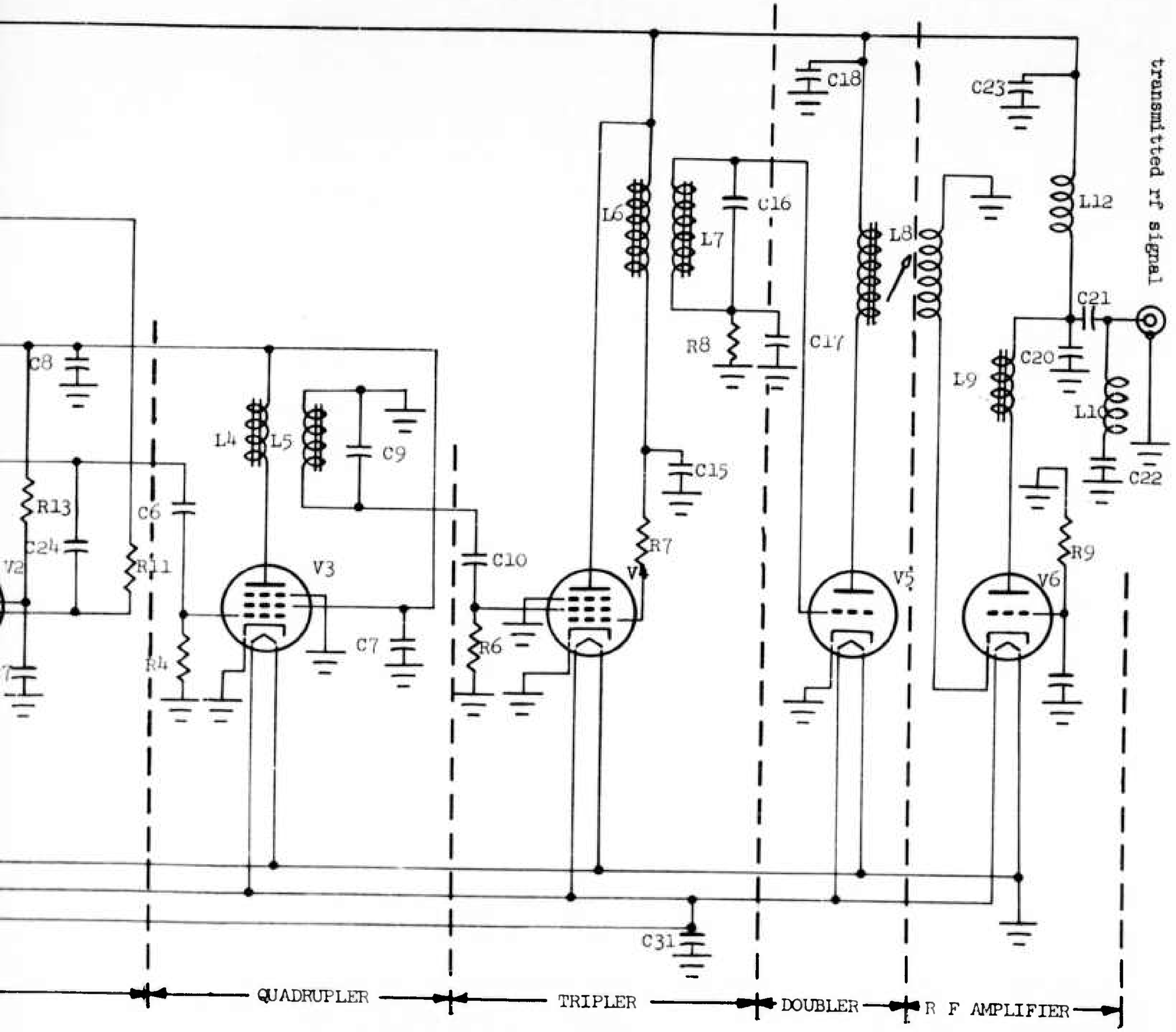


FIGURE 21 SCHEMATIC DIAGRAM FOR THE BENDIX TXV-1
(REFER TO TABLE 10 FOR E



RAM FOR THE BENDIX TXV-13 PM/FM TELEMETERING TRANSMITTER
(REFER TO TABLE 10 FOR ELEMENT VALUES)

TABLE 10
POST IRRADIATION EVALUATION FOR COMPONENTS OF
BENDIX TXV-13 PM/FM TELEMETERING TRANSMITTER
(REFERENCE SCHEMATIC DIAGRAM, FIGURE 21)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Resistor	R1	47K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R2	12K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R3	9.2K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R4	330K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R5	12K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R6	180K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R7	12K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R8	27K ohm	IRC	FN20X	Deposited carbon	Notes 1 & 2
Resistor	R9	1200K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R10	22K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R11	470K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2

TABLE 10 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Resistor	R12	1K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R13	27K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R14	270K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Resistor	R15	180K ohm	IRC	RN20X	Deposited carbon	Notes 1 & 2
Tube, Electron	V1		Sylvania	5702	Glass envelope sub miniature	Note 1
Tube, Electron	V2		Sylvania	5702	Glass envelope sub miniature	Note 1
Tube, Electron	V3		Sylvania	5702	Glass envelope sub miniature	Note 1
Tube, Electron	V4		Sylvania	5702	Glass envelope sub miniature	Note 1
Tube, Electron	V5		Sylvania	5703	Glass envelope sub miniature	Note 1
Tube, Electron	V6		Sylvania	5703	Glass envelope sub miniature	Grid-plate transconductance decreased 35%

TABLE 10 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Capacitor	C1	100 mfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C2	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C3	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C4	56 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C5	18 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C6	75 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C7	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C8	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C9	10 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C10	10 mmfd	El-Menco	Cm-15	Molded silver mica	Notes 1 & 3
Capacitor	C11	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C12	.015 mfd	Goodall		Metal & mylar	Notes 1 & 3

TABLE 10 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRADIATION EVALUATION
Capacitor	C13	.015 mfd	Goodall		Metal & mylar	Notes 1 & 3
Capacitor	C14	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C15	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C16	10 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C17	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C18	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C19	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C20	62 mmfd	Erie	370-CB 500K	Silver-ceramic	Notes 1 & 3
Capacitor	C21	470 mmfd	Sprague	56A-T47	Ceramic	Notes 1 & 3
Capacitor	C22	12 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C23	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C24	42 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3

TABLE 10 (CONTINUED)

ELEMENT	CODE	VALUE	VENDOR	TYPE	DESCRIPTION	POST IRRAIDATION EVALUATION
Capacitor	C25	200 mmfd	El-Menco	CM-15	Molded silver mica	Notes 1 & 3
Capacitor	C26	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C27	.1 mmfd	Goodall		Metal & mylar	Notes 1 & 3
Capacitor	C28	5 mmfd	Fan Steel	PP	Tantalum	Notes 1 & 3
Capacitor	C29	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C30	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C31	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Capacitor	C32	1K mmfd	Centra-lab	MFT 1000	Ceramic	Notes 1 & 3
Quartz Crystal	Y1	9.5833 Mc/sec.	M.P Co.	CR-18/U	1/24 of transmitter frequency	Less .01% frequency shift
Chokes	L2 thru L9		Miller		Phenolic formed core	Required adjustment after test, before trans. power could be attained.

TABLE 10 (CONTINUED)

NOTES:

1. Insignificant nuclear radiation induced changes occured.
2. All deposited carbon resistors are 0.5 watt $\pm$ 1%.
3. All capacitors are 500 volts or greater.

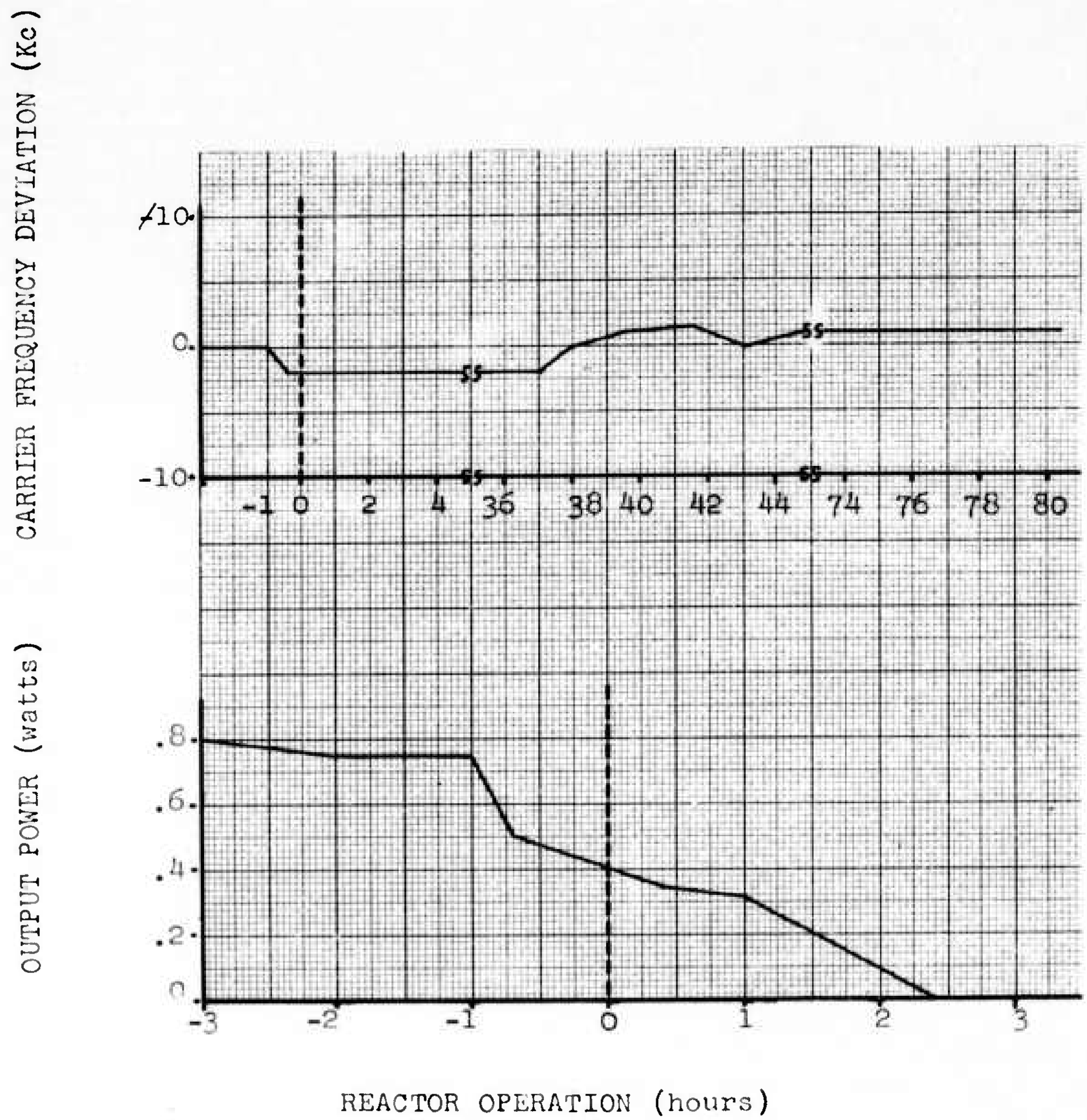


FIGURE 22 PM/FM 230 MC TELEMETERING TRANSMITTER OUTPUT

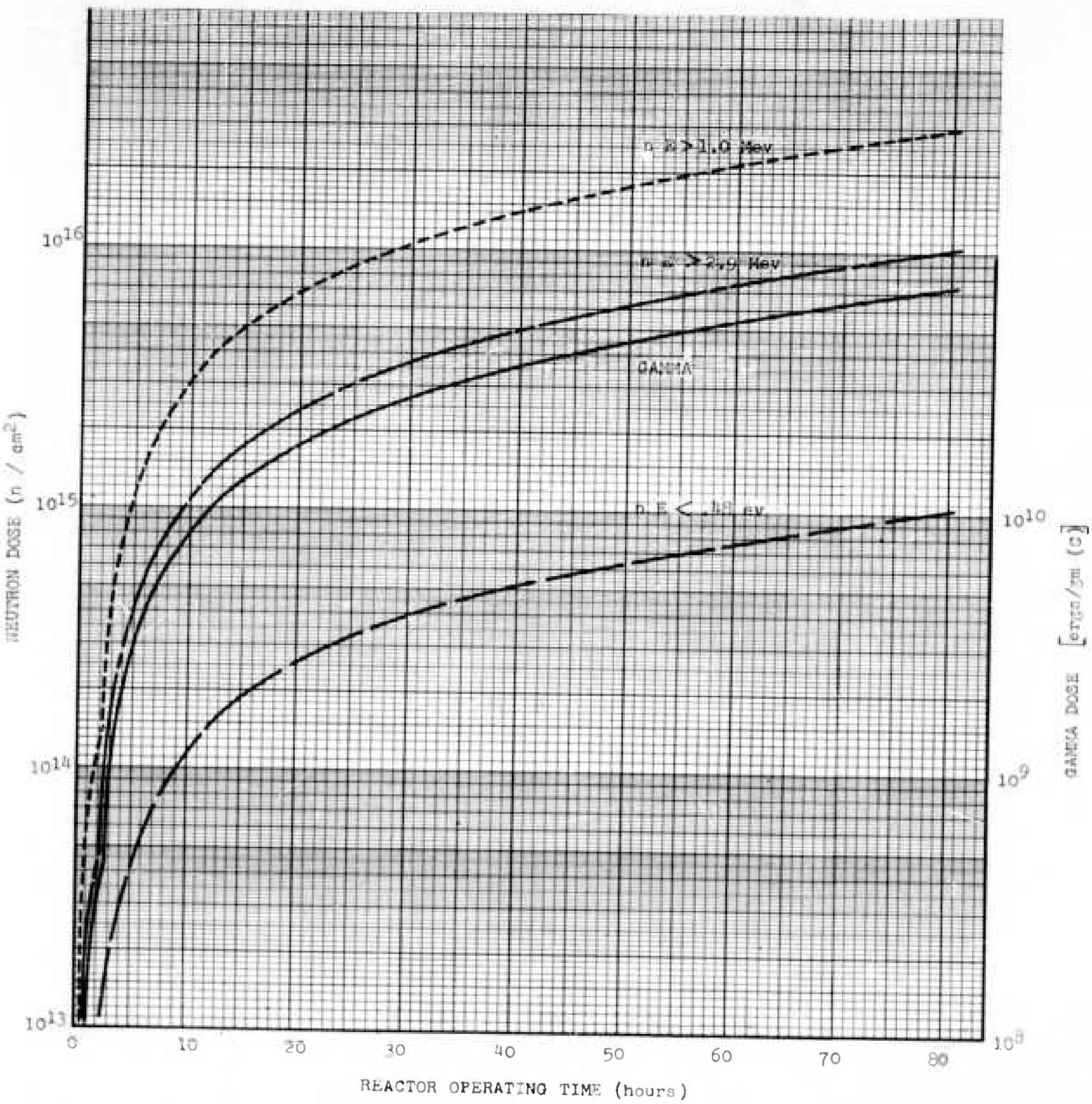


FIGURE 23 NUCLEAR RADIATION EXPOSURE FOR 230 Mc PM/FM TRANSMITTER

After failure of the mixer amplifier, the transmitter merely transmitted the carrier frequency. The irradiation continued for 78.33 hours after output power failure at which time carrier frequency had changed a negative 2 Kcs. Such a small variation indicated that the quartz crystal had maintained good frequency stability. The total nuclear radiation exposure was 7.5×10^{10} ergs/gm-(C) and 3.0×10^{16} n_f/cm^2 (Ref. Fig. 23).

Post irradiation evaluation tests were conducted to determine reasons for Bendix transmitter power failure. The grid-plate transconductance of V6, the subminiature glass envelope electron tube #5703, in the power amplifier stage had decreased 35%. After this tube was replaced, all efforts to restore a 2.0 watt output signal proved futile. Adjustment of chokes L2 through L9, Figure 21, resulted in a R. F. power output of 0.9 watts which would go to zero if further choke adjustment was attempted. It was concluded that initial low output power instability and eventual failure after 2.4 hours of nuclear reactor exposure was caused by a combination of incompatible electronic variables introduced by the nuclear radiation hardening modifications listed in Table 9. Physically larger replacement resistors and capacitors increased packing density to a critical value, which resulted in slight changes in R. F. wiring positions. Thus, failure of output R. F. power cannot be related to the interaction of nuclear radiation with electronic elements. Interaction of nuclear radiation exposure of 7.5×10^{10} ergs/gm-(C) and 3.0×10^{16} n_f/cm^2 with #5703 subminiature electron tube V6 (Fig. 21) contributed to a 35% reduction in its plate-grid transconductance.

2.6 Conclusions

The two, 216 to 260 Mcs band PM/FM and FM/FM crystal controlled telemetering transmitter systems were radiation hardened, irradiated, and analyzed in order to relate changes in electronic parameters with nuclear radiation exposure. Telemetering component modification, based upon nuclear radiation compatibility, significantly increased the limiting nuclear radiation exposure. The limiting nuclear radiation exposure was analytically determined for the unmodified condition and experimentally established for the modified component, and those results support the practicality of extending the nuclear environment compatibility of existing telemetering systems.

The "limited modification" concept of this investigation did not permit complete utilization of currently available electronic elements which could have extended nuclear environmental capabilities. Data generated in this investigation did not furnish a complete solution to the problem under consideration, but it did establish the basis for a more comprehensive test. Specific recommendations are called out in the discussion of each telemetering system component which follows:

2.6.1 Miniature Subcarrier Oscillator, Vector Type S-81B.

The two voltage controlled miniature subcarrier oscillators

irradiated were identical except for capacitors C1 and C2 in the multivibrator stage (Ref. Fig. 5 and 6), which established the SCO output frequencies of 10.5 and 14.5 Kc, respectively. Based on the radiation effects analysis of the unmodified SCO, a limiting nuclear radiation exposure potential of 1.0×10^7 ergs/gm-(C) and 1.0×10^{16} n_f/cm^2 was established. Teflon insulated electrical wire and subminiature glass envelope electron tubes number 6111 were the limiting gamma and neutron sensitive electronic elements, respectively. Nuclear radiation test results of the modified SCO's indicated that the limiting nuclear radiation exposure had been increased to 1.3×10^9 ergs/gm-(C), based on deposited carbon resistor failure (Ref. R3 and R7 Fig. 6) and greater than 3.0×10^{16} n_f/cm^2, which reflects the fact that no predominant neutron sensitive electronic elements failed during the irradiation. Modification of the SCO's increased the packing density beyond a desirable limit and resulted in a reduced heat dissipation factor.

A logical extension of the study of the SCO would include breadboard circuits to eliminate overheating, extended radiation oriented modifications, calibration of electronic elements, unpotted filter, larger number of circuit monitoring points, and extensive post irradiation testing.

2.6.2 Miniature Mixer Amplifier, Vector Type A-80

Observation of the modified mixer amplifier's performance was prematurely discontinued during the irradiation because of SCO failure; therefore, failures detected during the post irradiation test could not be identified with a particular nuclear radiation exposure. The unmodified mixer had a limiting nuclear radiation exposure potential of 1.0×10^7 ergs/gm-(C) and 1.0×10^{16} n_f/cm^2. Teflon insulated electrical wire and subminiature glass envelope electron tube number 6111 were the limiting gamma and neutron sensitive electronic elements, respectively. Post irradiation tests revealed that the only failure was the V1 electron tube (Ref. Fig. 13). Since this tube was one out of nine number 6111 electron tubes included in the test, its failure was probably a consequence of random failure attributed to non-nuclear causes. On this basis then the mixer amplifier's limiting nuclear radiation exposure would be in excess of the total irradiation exposure of 7.9×10^{10} ergs/gm-(C) and 2.8×10^{16} n_f/cm^2 (Ref. Fig.11). As in the case of the SCO's, modification of the mixer amplifier produced an undesirable decrease in heat dissipation.

A logical extension of this test to completely define the maximum limiting nuclear radiation of the mixer amplifier would include the same things outlined for the SCO with the addition of eliminating the dependence of the mixer amplifier on the SCO output signal.

2.6.3 Telechrome Model 1472-A FM/FM Subminiature Telemetering Transmitter

The unmodified transmitter had a limiting nuclear radiation

exposure of 1.0×10^7 ergs/gm-(C) and 1.0×10^{14} n_f/cm^2. Teflon electrical wire insulation and number 301 silicon diode were the limiting gamma and neutron sensitive electronic components. Modification of the transmitter increased the limiting nuclear radiation exposure to 3.7×10^8 ergs/gm-(C) and 1.0×10^{14} n_f/cm^2 which was the failure dose of the Telechrome SP-14114-1-2 quartz crystal (Ref. Fig. 8). Power failure occurred at a higher nuclear radiation exposure of 2.0×10^{10} ergs/gm-(C) and 6.0×10^{15} n_f/cm^2, which was attributed to small nuclear radiation induced changes in resistors, capacitors, and electron tubes; however, none of these components actually completely failed. Limited time and scope of test prevented substitution of a more radiation tolerant crystal unit. This substitution in addition to those listed in Table 7 would have increased the limiting nuclear radiation exposure to 2.0×10^{10} ergs/gm-(C) and 6.0×10^{15} n_f/cm^2.

2.6.4 Bendix Model TXV-13 PM/FM Telemetering Transmitter

Modification of the Bendix transmitter (Ref. Table 9) introduced an output R. F. power instability that was not solved prior to testing; consequently, output power failure occurred prematurely after a nuclear radiation exposure of 8.0×10^8 ergs/gm-(C) and 3×10^{14} n_f/cm^2. Carrier frequency was monitored throughout the irradiation with less than .01% deviation occurring. The total nuclear radiation exposure was 7.5×10^{10} ergs/gm-(C) and 3.0×10^{16} n_f/cm^2.

A logical extension of this test would be to repeat the test using 100 watt PM/FM and FM/FM transmitters operating in the 1435 to 1535 Mcs band with increased emphasis on more extensive radiation hardening, establishing reliable operation prior to irradiation, use of an external ac voltage modulation source and extensive post irradiation testing. The 100 watt, 1435 to 1535 Mcs PM/FM and FM/FM telemetering transmitter is suggested for it is anticipated for future use in flight test vehicles utilizing nuclear energy propulsion systems.

In addition to radiation-hardening the telemetry subsystem, an experimental investigation should be made of the problems associated with propagating an electromagnetic signal through the ionized medium surrounding a nuclear powered vehicle.

III. TRANSDUCERS

3.1 Introduction

Ten representative transducers were utilized as variable voltage inputs to the telemetry system, as shown in Figure 1. They were dynamically irradiated in the 3 Mw Ground Test Reactor for 80.7 hours (237 Mw hrs.) as part of the telemetry system. The transducers were of the pressure and angular displacement type utilizing the potentiometer principle. Table 11 lists the irradiated transducers.

TABLE 11

IRRADIATED POTENTIOMETER TYPE TRANSDUCERS

Description	Vendor	Model	Serial No.
0 to 15 PSIG Pressure Transducer	Giannini	451224-G-1.5-95	38
0 to 30 PSIG " "	"	451218	3234
0 to 1500 PSIG " "	"	46119Y	1421
0 to 4000 PSID " "	"	46155-H-D	3644
0 to 150 PSIA " "	Trans-Sonic	2115	11
0 to 4000 PSID " "	Bourns	70624	2421
Double Angular Position Transducer	Markite	3108	-
Double Angular Position Transducer	Fairchild	747E	-

The potentiometer type transducer, as utilized in this investigation, is defined as a sensor employing a resistance voltage divider to convert the input mechanical stimulus, either an applied pressure or rotary motion, into a variable voltage. Changes in the measurand result directly or indirectly in a change in the position of the potentiometer's slider, and if the potentiometer is supplied with constant direct current, result in a change in the amplitude of the output voltage. The potentiometer windings in most cases consist of a tightly wound coil of very fine wire.

All pressure transducers were mounted on the rear of the test pallet in a plane perpendicular to and approximately 30 inches from the east face of the reactor closet. The general location of the pressure transducers is shown in Figure 24. Two ganged angular position transducers were positioned in the center of the pallet above the servo actuator output arm, as shown in Figure 25, and parallel to the east face of the reactor closet. The actuator output arm was used to

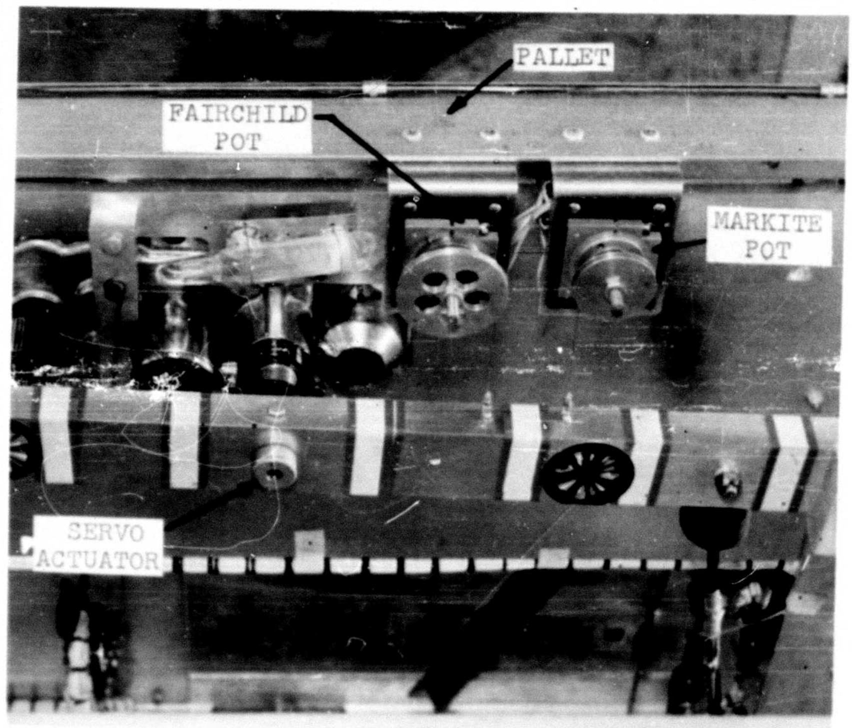


FIGURE 24 PRESSURE TRANSDUCERS ON TEST PALLET

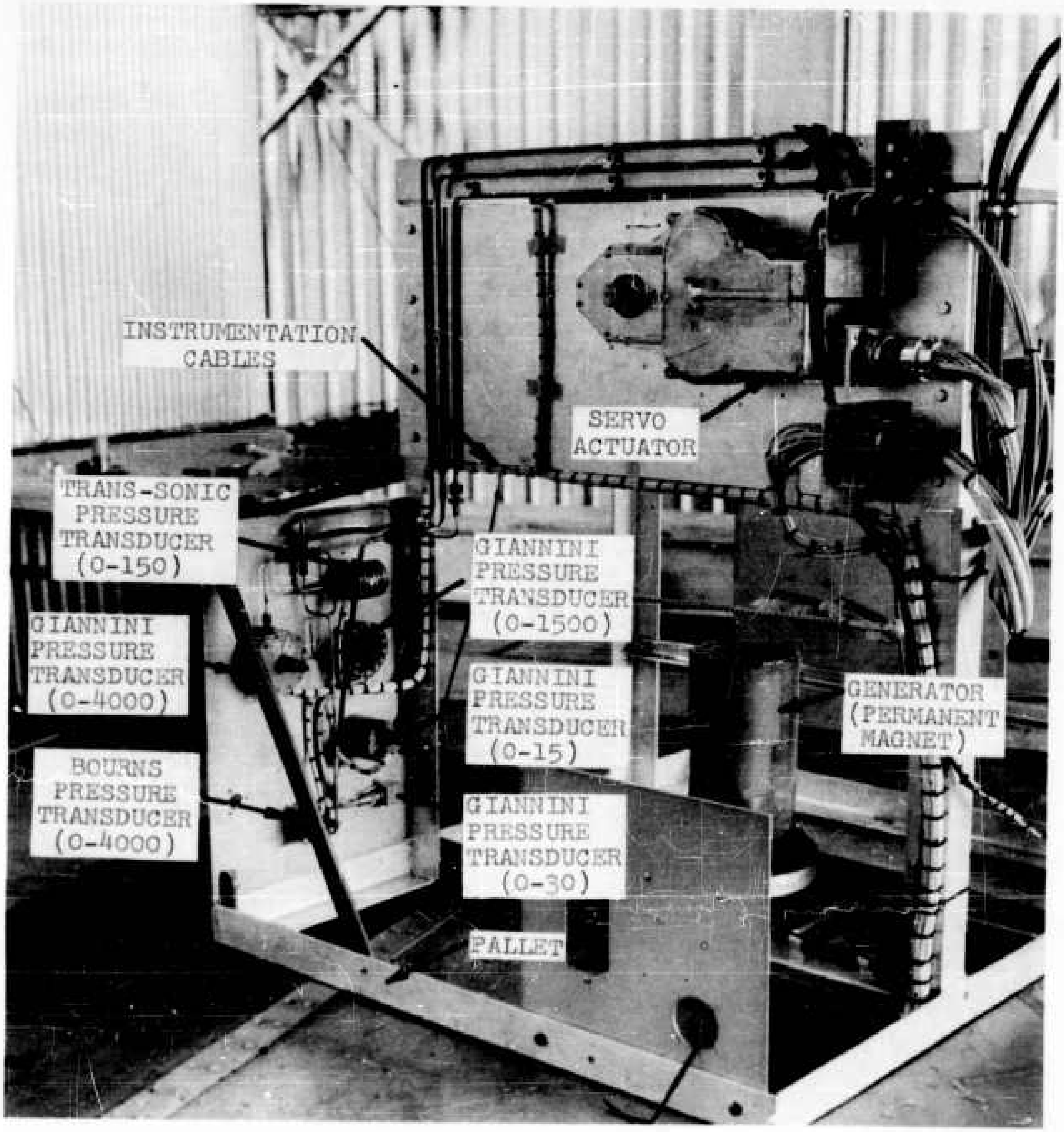


FIGURE 25 ANGULAR POSITION POTENTIOMETERS ON TEST STAND

drive the angular position potentiometers through the cable pulley arrangement (Ref. Fig. 25).

3.2 0 to 15 PSIG Pressure Transducer, Giannini Model 451224-G-1.5-95

The Model 451224 pressure transducer contains a pressure responsive capsule which actuates a precision potentiometer providing an output linear with applied pressure from 0 to 15 psig. The transducer is hermetically sealed and is designed to withstand severe vibration. Complete specifications for this transducer are given in Appendix B5. Giannini modified the transducer for maximum radiation tolerance by replacing all organic electric wire insulation with a ceramic insulation.

This transducer was damaged as a result of accidental overpressuring during the course of the irradiation, which resulted in a permanent deformation of the pressure responsive capsule. Figure 26 is the pre- and post calibration curves for the transducer showing the results of overpressuring the transducer. The nuclear radiation exposure is presented in Figure 27.

Post irradiation disassembly did not reveal any apparent nuclear radiation induced damage. The very nature of the hardened pressure transducer and the fact that the nuclear radiation exposure was below the threshold for metals damage precluded any such damage.

3.3 0 to 30 PSIG Pressure Transducer, Giannini Model 451218

The Model 451218 pressure transducer contains a pressure sensitive NI-SPAN C capsule which actuates the brush of a precision potentiometer through a low friction multiplication mechanism. Noble metal alloys are used for both windings and brushes. This permits low brush pressure resulting in low noise. Linearity of the instrument is better than $\pm$ 1.5% of full scale and repeatability and hysterisis errors are less than 1.0%. Complete specifications for the transducer are given in Appendix B6. Giannini modified the transducer for maximum radiation tolerance by replacing all organic electrical wire insulation with a ceramic insulation.

The transducer was irradiated for a total of 80.7 hours (237 Mw hours) and received a nuclear radiation exposure of 2.9×10^{10} ergs/gm-(C) and 7.2×10^{15} n_f/cm^2 (Ref. Fig. 27). The output varied less than $\pm$ 1% during the first 49 hours of the irradiation (a nuclear radiation exposure of 1.7×10^{10} ergs/gm-(C) and 3.3×10^{15} n_f/cm^2). At that time the signal was lost due to instrumentation failure.

Post irradiation calibration (Fig. 28) revealed that wiper movement was zero over the pressure range of the transducer. This failure occurred after the loss of instrumentation, and hence there is no record of the exact time. Post irradiation disassembly and test indicated that the brush actuation mechanism was not binding, that

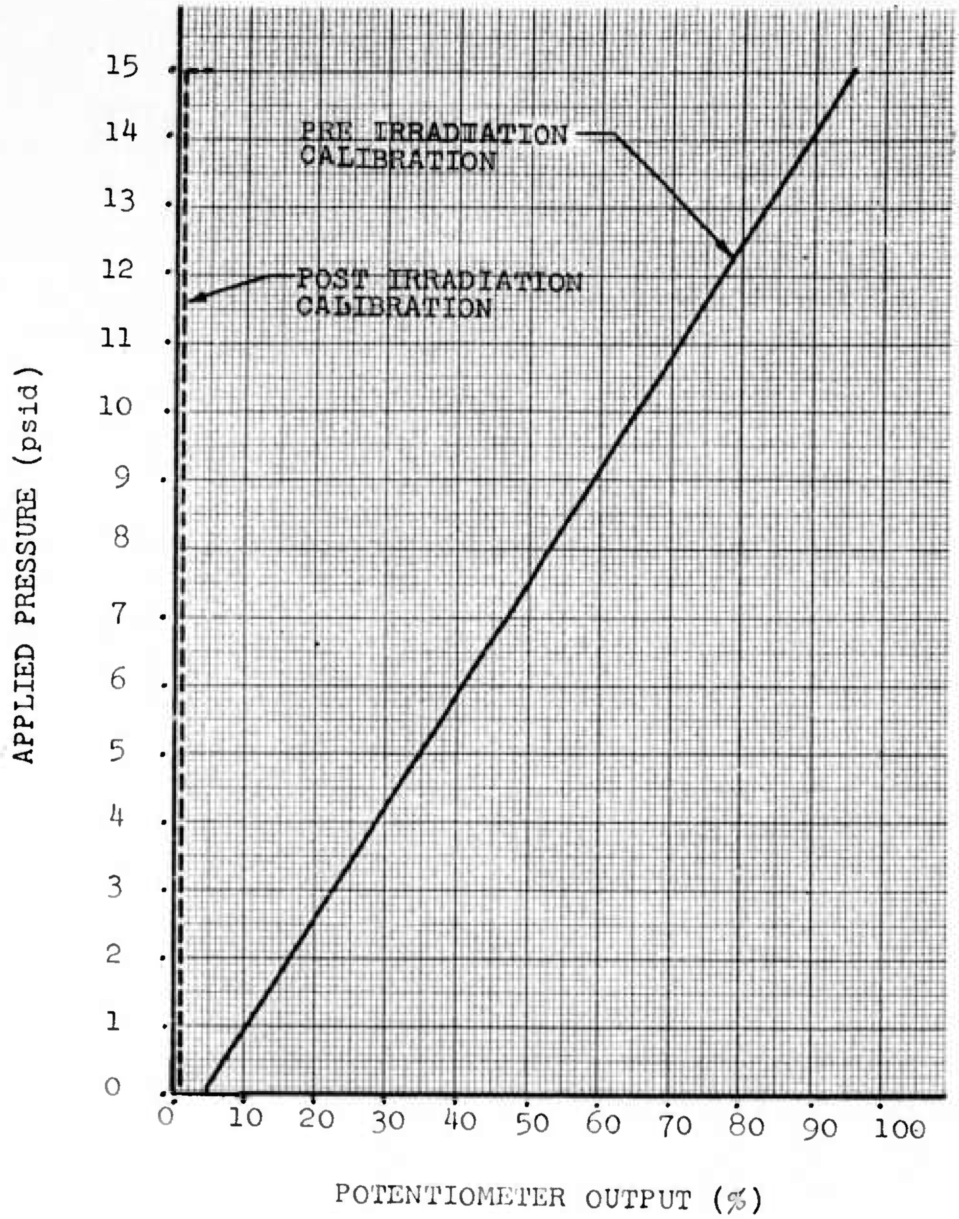


FIGURE 26 CALIBRATION CURVES FOR THE 0 TO 15 PSIG GIANNINI PRESSURE TRANSDUCER MODEL 451224

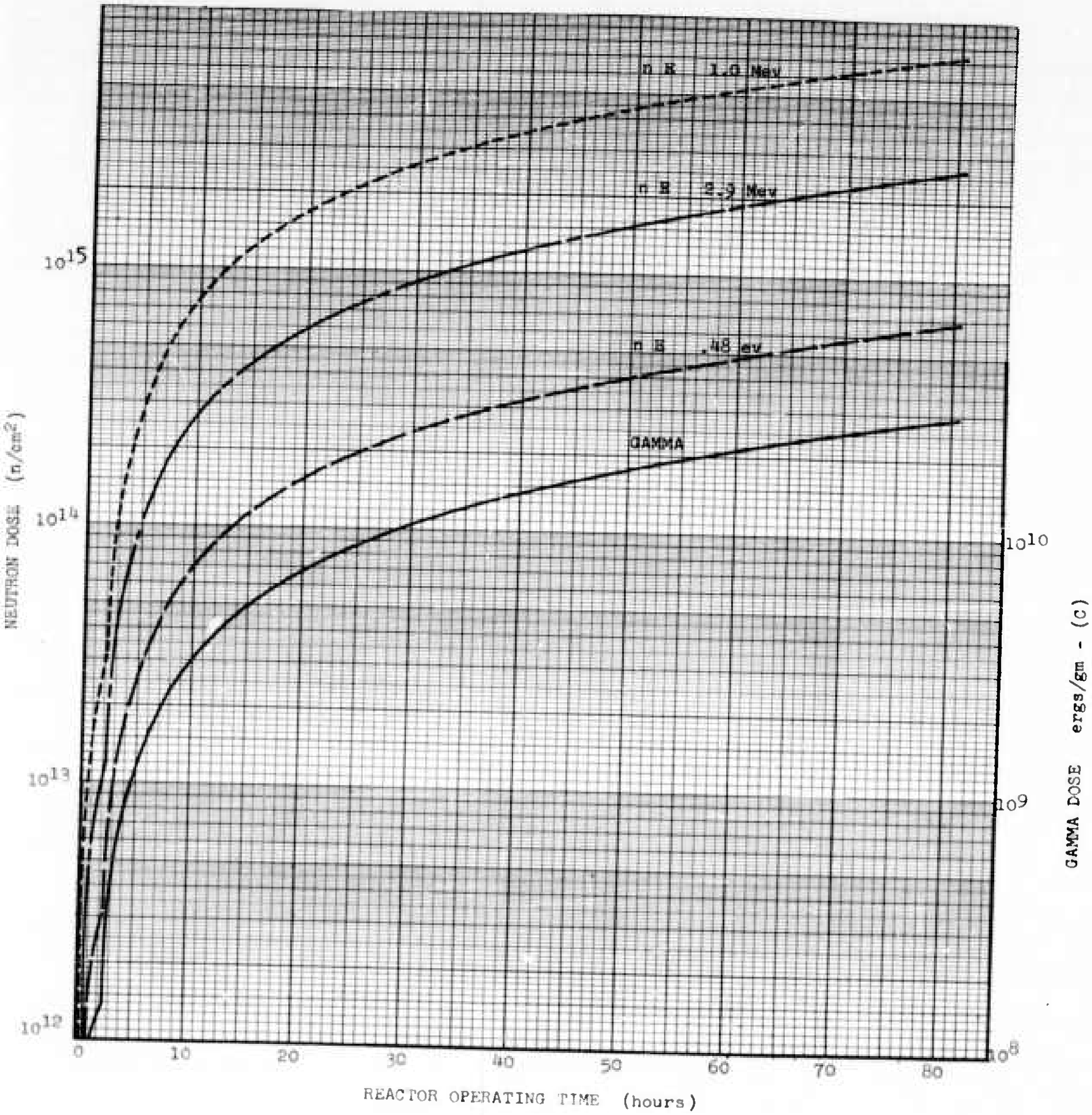


FIGURE 27 NUCLEAR RADIATION EXPOSURE FOR THE 0-15 PSIG AND 0-30 PSIG PRESSURE TRANSDUCERS

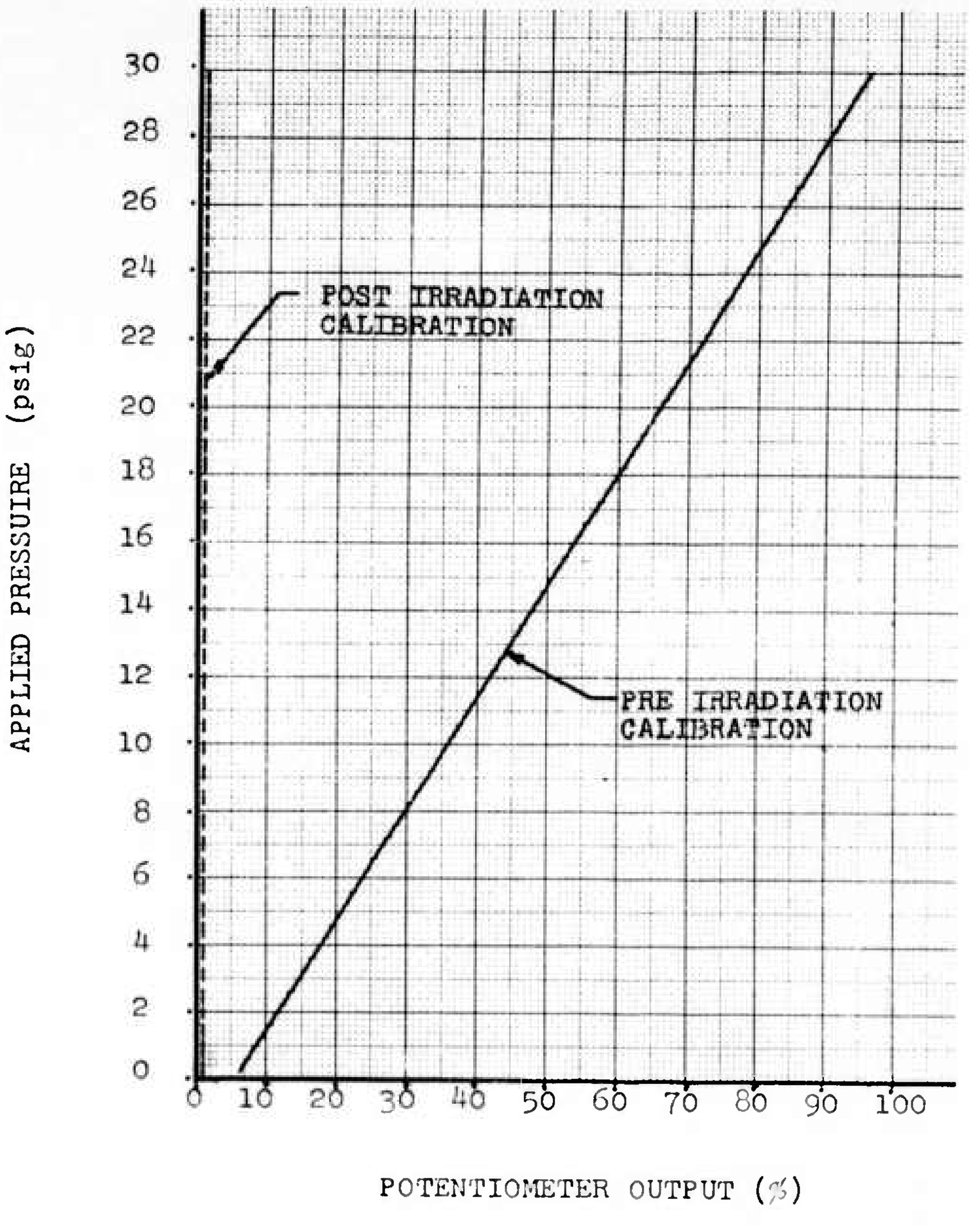


FIGURE 28 CALIBRATION CURVES FOR THE 0 TO 30 PSIG GIANNINI PRESSURE TRANSDUCERS MODEL 451218

wiper movement could be initiated and there was continuity between wiper and coil for all positions. It was concluded that there was no basis for radiation damage, and hence failure was attributed to normal random failure of an unknown origin.

3.4 0 to 1500 PSIG Pressure Transducer, Giannini Model 46119Y

Giannini Model 46119Y Bourdon type pressure transducer was designed to accurately translate pressure into convenient electrical signals that are directly proportional to the applied pressure. Noble metals were used for potentiometer coils and brushes. The pressure sensing element, a 1.8 inch nominal diameter berylium copper or NI-SPAN C Bourdon tube, employed a center suspension that permitted the use of direct coupling arrangement between the tube and the potentiomenter element. The design provided movement amplification, without the use of gearing or linkage of any kind. The instrument used in the irradiation was a standard off-the-shelf model. Complete specifications for the transducer are given in Appendix B7.

The transducer was irradiated for a total of 80.7 hours (237 Mw hours) and received a nuclear radiation exposure of 2.3×10^{10} ergs/gm-(C) and 6.7×10^{15} n_f/cm^2 (Ref. Fig. 29). Its output versus input never varied more than 1.85% during the first 49 hours of irradiation, at which time the output signal was lost due to instrumentation failure. Comparison of the pre- or post irradiation curves indicated that the pressure transducer had not changed (Ref. Fig. 30) as a result of the irradiation.

3.5 0 to 4000 PSID Pressure Transducer, Giannini Model 46155-H-D

The pressure transducer consists of a pressure responsive Bourdon tube which actuates a precision potentiometer. It is oil filled with DC 510 silicone fluid to increase its ability to withstand severe vibration. Complete specifications are contained in Appendix B8. The pressure transducer was not modified before it was irradiated.

The transducer was irradiated for a total of 80.7 hours (237 Mw hours) and received a nuclear radiation exposure of 2.4×10^{10} ergs/gm-(C) and 5.1×10^{15} n_f/cm^2 (Ref. Fig. 31). After 29 hours of irradiation the response of the pressure transducer degraded 8% and continued to degrade until an instrumentation failure terminated the transducer output signal. The nuclear radiation exposure for the pressure transducer after 29 hours of irradiation was 8.5×10^9 ergs/gm-(C) and 1.8×10^{15} n_f/cm^2, which represents a failure dose of the transducer. Post irradiation calibration revealed that there was no particular relationship between pressure and the output voltage (Ref. Fig. 32). Disassembly of the pressure transducer revealed that the DC 510 silicone fluid had formed a solid mass and was restricting the movement of the wiper assembly. DC 550 has a significant viscosity increase after a nuclear radiation exposure of

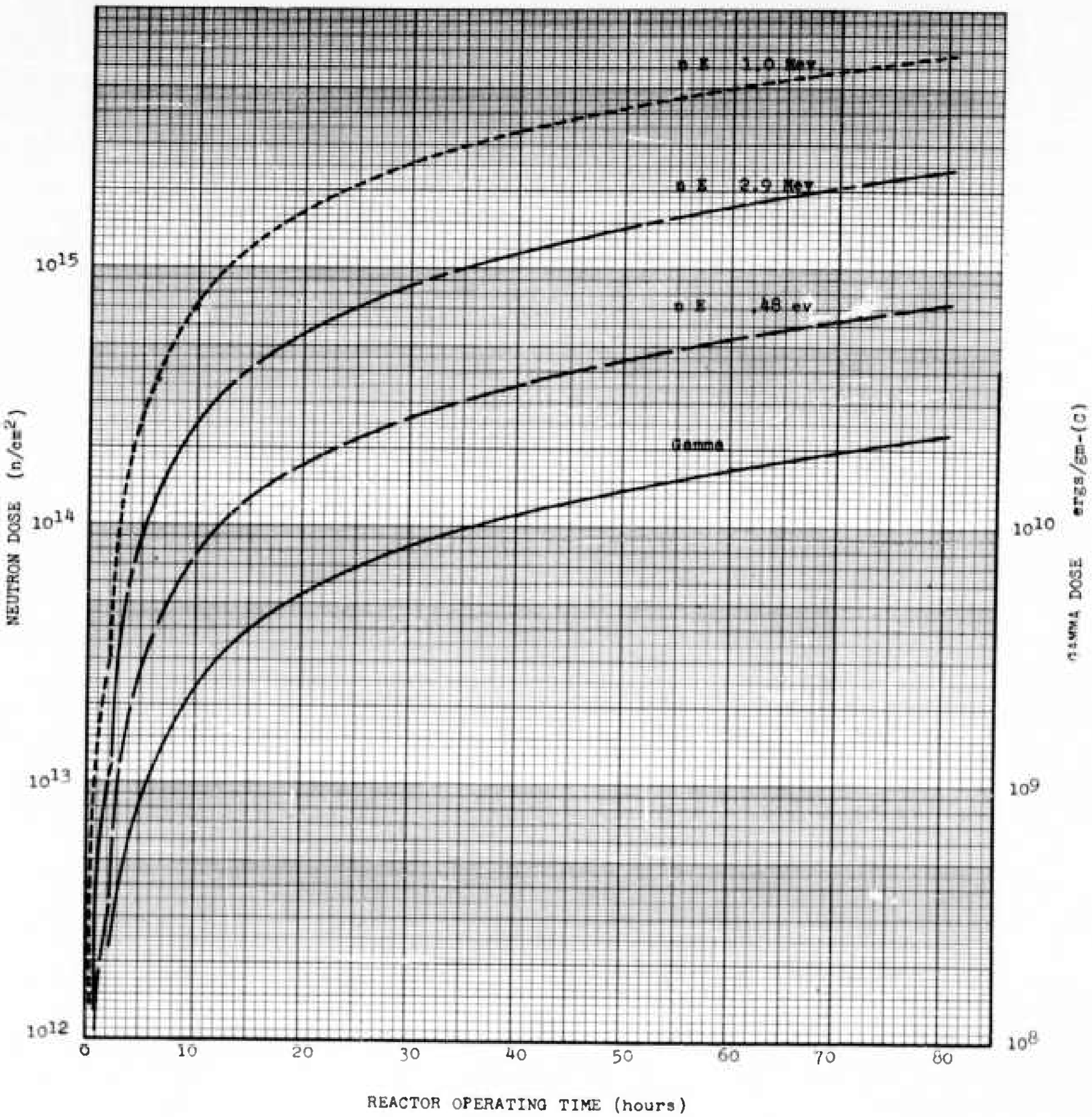


FIGURE 29 NUCLEAR RADIATION EXPOSURE OF 0 TO 1500 PSIG GIANNINI AND 0 to 150 PSIA PRESSURE TRANSDUCERS

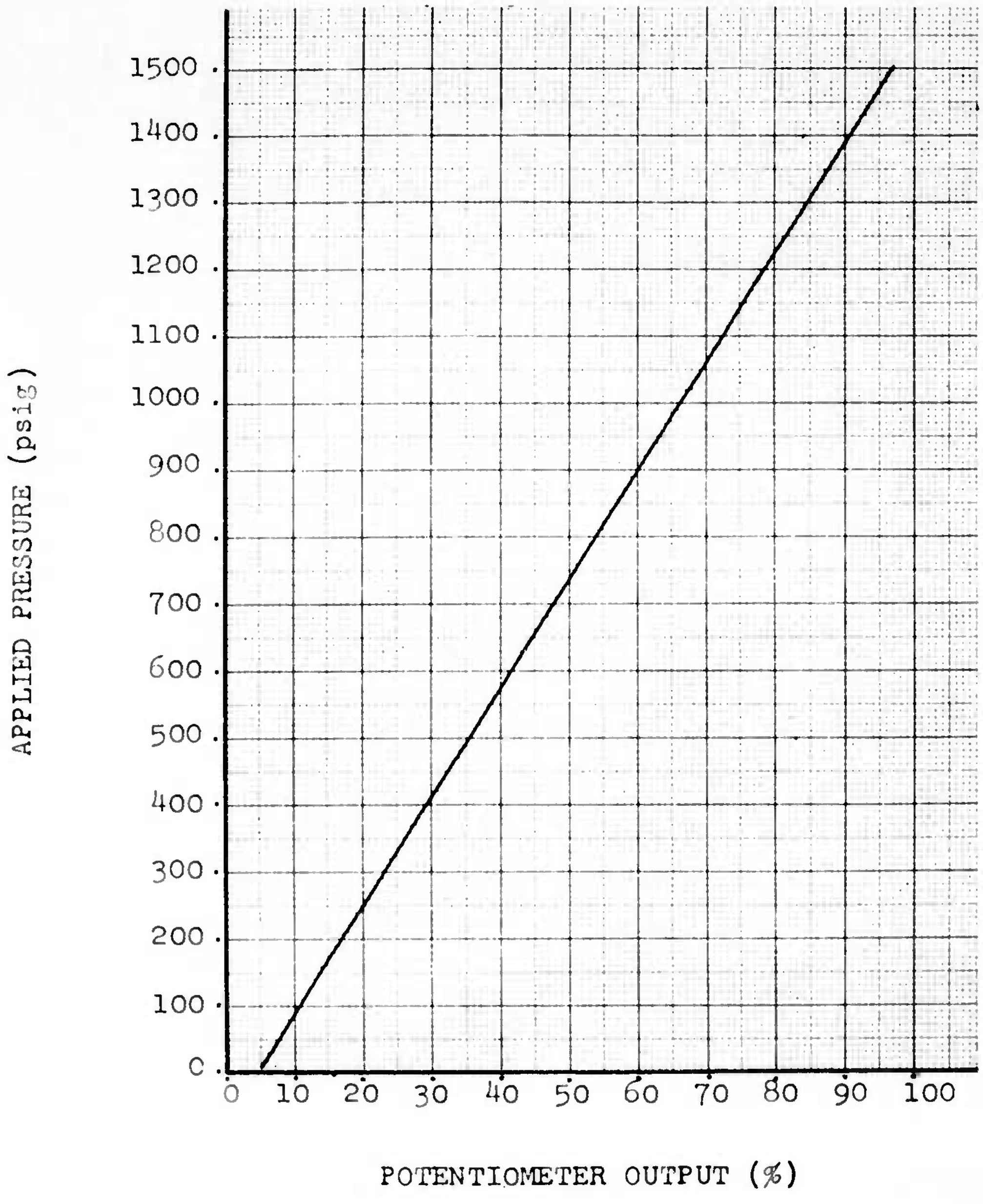
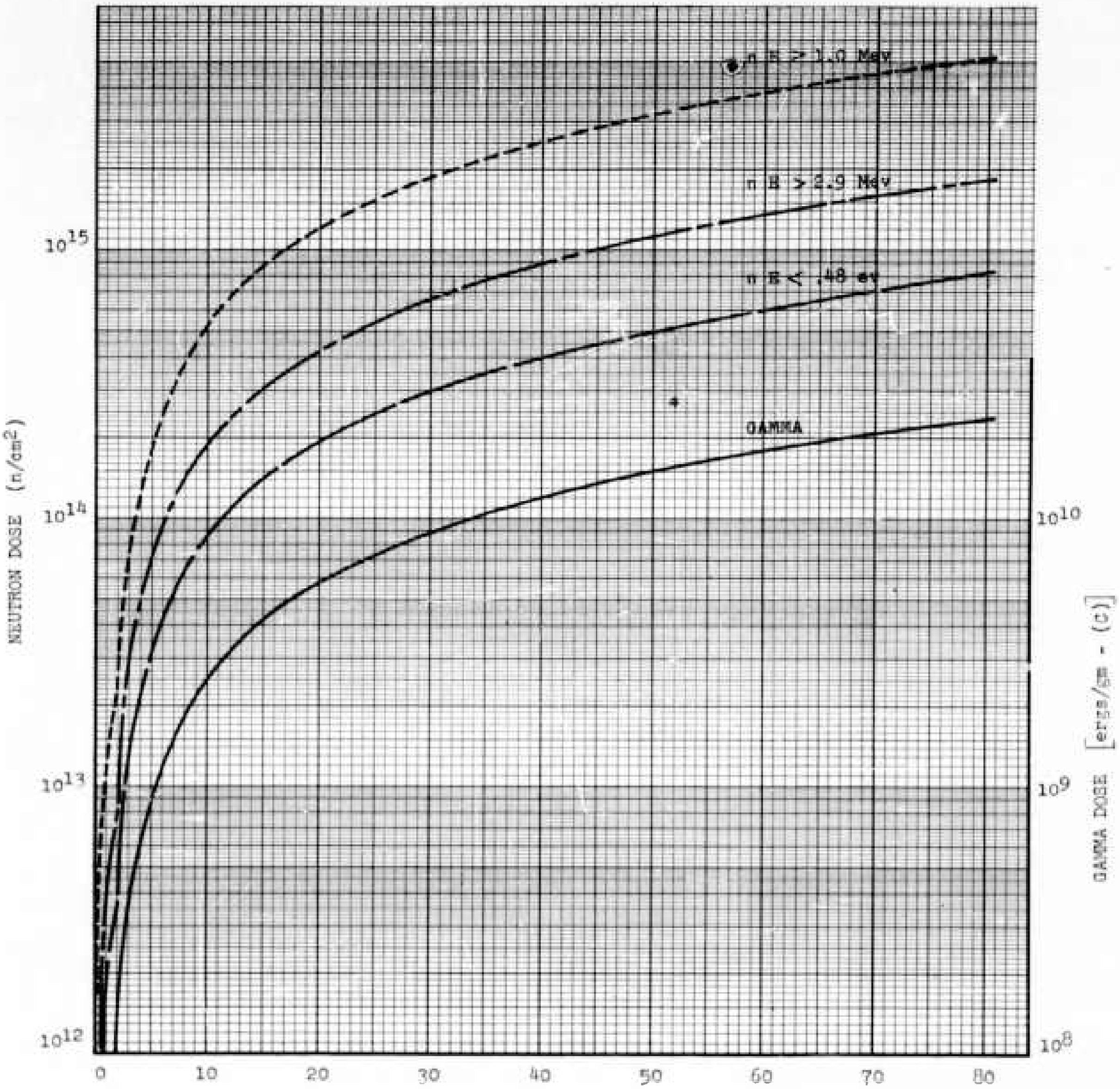


FIGURE 30 CALIBRATION CURVES FOR THE 0 TO 1500 PSIG GIANNINI PRESSURE TRANSDUCER MODEL 46119Y



REACTOR OPERATING TIME (Hours)

FIGURE 31 NUCLEAR RADIATION EXPOSURE FOR 0 TO 4000 PSID GIANNINI PRESSURE TRANSDUCER

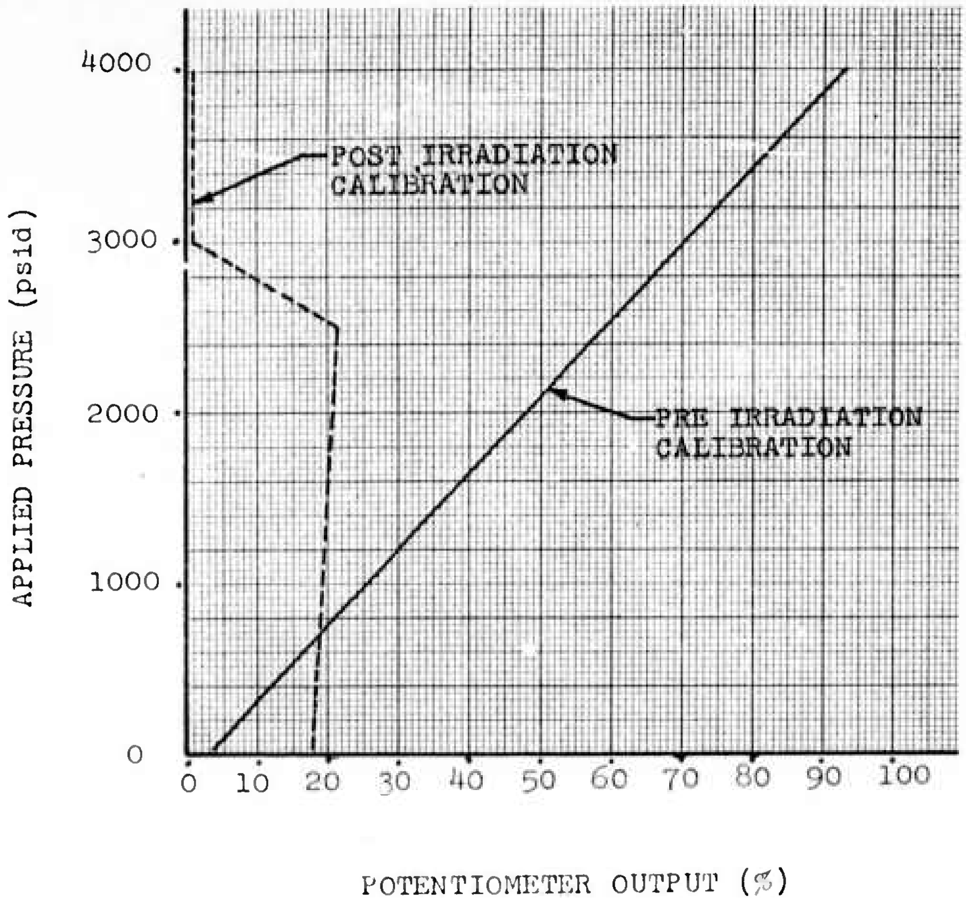


FIGURE 32 CALIBRATION CURVES FOR THE 0 TO 4000 PSID GIANNINI PRESSURE TRANSDUCER MODEL 46155-H-D

3.0×10^9 ergs/gm-(C), which would result in the variations in transducer response evidenced after 29 hours of irradiation.

3.6 0 to 150 PSIA Pressure Transducer, Trans-Sonic Model 2115

An off-the-shelf 0 to 150 psia Trans-Sonic pressure transducer was irradiated for a total of 80.7 hours (237 Mw hours) and received a nuclear radiation exposure of 2.3×10^{10} ergs/gm-(C) and 6.7×10^{15} n_f/cm^2. During the test a maximum of 6.5% output error occurred, but post irradiation calibration was identical with the pre-irradiation calibration values. Post irradiation disassembly did not reveal any visible nuclear radiation induced degradation of the transducer.

3.7 0 to 4000 PSID Pressure Transducer, Bourns Model 2421

An off-the-shelf 0 to 4000 psid Bourns Model 2421 pressure transducer was irradiated for a total of 80.7 hours (237 Mw hours) and received a nuclear radiation exposure of 2.1×10^{10} ergs/gm-(C) and 5.4×10^{15} n_f/cm^2. During the irradiation the output signal error was a maximum of 2.5% and post irradiation calibration agreed with the pre-irradiation calibration. Post irradiation disassembly did not reveal any visible nuclear radiation induced degradation of the transducer.

3.8 Double Angular Position Transducer, Markite Model 3108

An unmodified Markite Model 3108 ganged angular position transducer was irradiated for 80.7 hours (237 Mw hours) for a total nuclear radiation exposure of 3.1×10^{10} ergs/gm-(C) and 7.6×10^{15} n_f/cm^2. It was actuated continuously throughout the irradiation by the servo actuator output arm through a pulley and cable mechanism (Ref. Fig. 25). The transducer output voltage was monitored until an instrumentation failure terminated the signal after 29 hours of irradiation. At that time the transducer was functioning correctly. A post irradiation continuity check of the transducer revealed that it had failed sometime after instrumentation failure. Failure was attributed to electrical wire insulation breakdown resulting from nuclear radiation damage.

3.9 Double Angular Position Transducer, Fairchild Model 747E

A unmodified Fairchild Model 747E ganged angular position transducer was irradiated for 80.7 hours (237 Mw hours) for a total nuclear radiation exposure of 3.1×10^{10} ergs/gm-(C) and 7.6×10^{15} n_f/cm^2. It was actuated continuously throughout the irradiation by the servo actuator output arm through a pulley and cable mechanism (Ref. Fig. 25). The transducer output voltage was monitored until a instrumentation failure terminated the signal after 29 hour of irradiation. At that time the transducer was functioning correctly. A post irradiation continuity check of the transducer revealed that it had

failed sometime after instrumentation failure. Failure was attributed to electrical wire insulation breakdown resulting from nuclear radiation damage.

3.10 Conclusions

A summary of the transducer irradiation is contained in Table 12.

TABLE 12

SUMMARY OF TRANSDUCER IRRADIATION

TRANSDUCER (Potentiometer Type)					Nuclear Radiation Exposure		Post Irradiation Evaluation
Type	Manufacturer	Range	Model	Serial Number	n_f/cm^2	ergs/gm-(C)	
Pressure	Giannini	0 to 15 PSIG	451224 (Modified)	38	7.2(15)*	2.9(10)*	The transducer was accidentally overpressured early in the irradiation, thus voiding test results
Pressure	Giannini	0 to 30 PSIG	451218 (Modified)	3234	7.2(15)*	2.9(10)*	Instrumentation failure prevented detection of failure point, but failure was attributed to a unknown non-nuclear cause
Pressure	Giannini	0 to 1500 PSIG	46119Y	1421			Functioned within tolerances throughout irradiation

TABLE 12 (Continued)

TRANSDUCER (Potentiometer Type)					Nuclear Radiation Exposure		Post Irradiation Evaluation
Type	Manufacturer	Range	Model	Serial Number	n_f/cm^2	ergs/gm-(C)	
Pressure	Giannini	0 to 4000 PSID	46155-H-D (Modified)	3644	5.1(15)*	2.4(10)*	DC 510 Silicone Fluid jelled after a nuclear radiation exposure of 8.5(9)ergs/gm-(C) and 1.8 (15)n_f/cm^2 which occurred after 29 hours of irradiation. That was selected as the failure point
Pressure	Trans-Sonic	0 to 150 PSIA	2115	11	6.7(15)*	2.3(10)*	Functioned within tolerances throughout irradiation
Pressure	Bourns	0 to 4000 PSID	70624	2421	5.4(15)*	2.1(10)*	- - - - - - -
Angular Position	Markite	-	3108	-	7.6(15)*	3.1(10)*	Failure caused by electrical wire insulation degradation resulting from nuclear radiation damage

TABLE 12 (Continued)

TRANSDUCER (Potentiometer Type)					Nuclear Radiation Exposure		Post Irradiation Evaluation
Type	Manufacturer	Range	Model	Serial Number	nf/cm2	ergs/gm-(C)	
Angular Position	Fairchild	-	747E	-	7.6(15)*	3.1(10)*	Failure caused by electrical wire degradation resulting from nuclear radiation damage

*(x) indicates powers of tens

IV. ELECTRON MULTIPLIER PHOTOTUBES

4.1 Introduction

An electron multiplier phototube utilizes the phenomenon of secondary emission to amplify signals composed of electron streams. Initially the process begins when light photons impinge on the cathode liberating electrons by the mechanics of photoelectron emission. These photoelectrons are multiplied in successive dynode stages by the process of secondary emission. These basic principles of operation indicates that the photomultiplier tube should be sensitive to gamma photon energy. More specifically the inherent dark current of the tube should be related to gamma photon dose rate.

A very small dark current (anode current) is observed when voltage is applied to the electrodes of the photomultiplier tube in complete darkness. This current has a component caused by a leakage, and a component consisting of pulses produced by electrons thermionically released from the cathode, by secondary electrons released by ionic bombardment of the dynodes or cathode, or by cold emission from the electrodes. The magnitude of the dark current establishes a limit below which the exciting radiation on the cathode cannot be detected.

4.2 Irradiation Procedure

Two RCA 5819, 10 stage, S-11 spectrum photomultiplier tubes and two DuMont 6292, 10 stage, S-11 spectrum photomultiplier tubes were irradiated by Chance Vought in General Dynamics 3000 curies Co^{60} gamma source on October 1, 1961. The testing apparatus employed for the irradiation is shown in Figures 34, 35, and 36. The purpose of this experiment was to investigate the sensitivity of the photomultipliers to light radiation while in the presence of nuclear radiation. This was accomplished by exposing the tubes to a GE 313 tungsten lamp operated at various currents before, during and after exposure to gamma photon dose rates listed below:

Position	Center of Volume	% Variation at Edge of 8" Cell
1	2.2×10^{7} ergs/gm-(C)hr	10%
2	1.7×10^{6} ergs/gm-(C)hr	10%

The photomultipliers were mounted on a common base inside a 7½" aluminum cylinder 8 inches long. The light source was centrally located on the base between the photomultipliers so that the light would be diffused by reflection inside the aluminum cylinder before

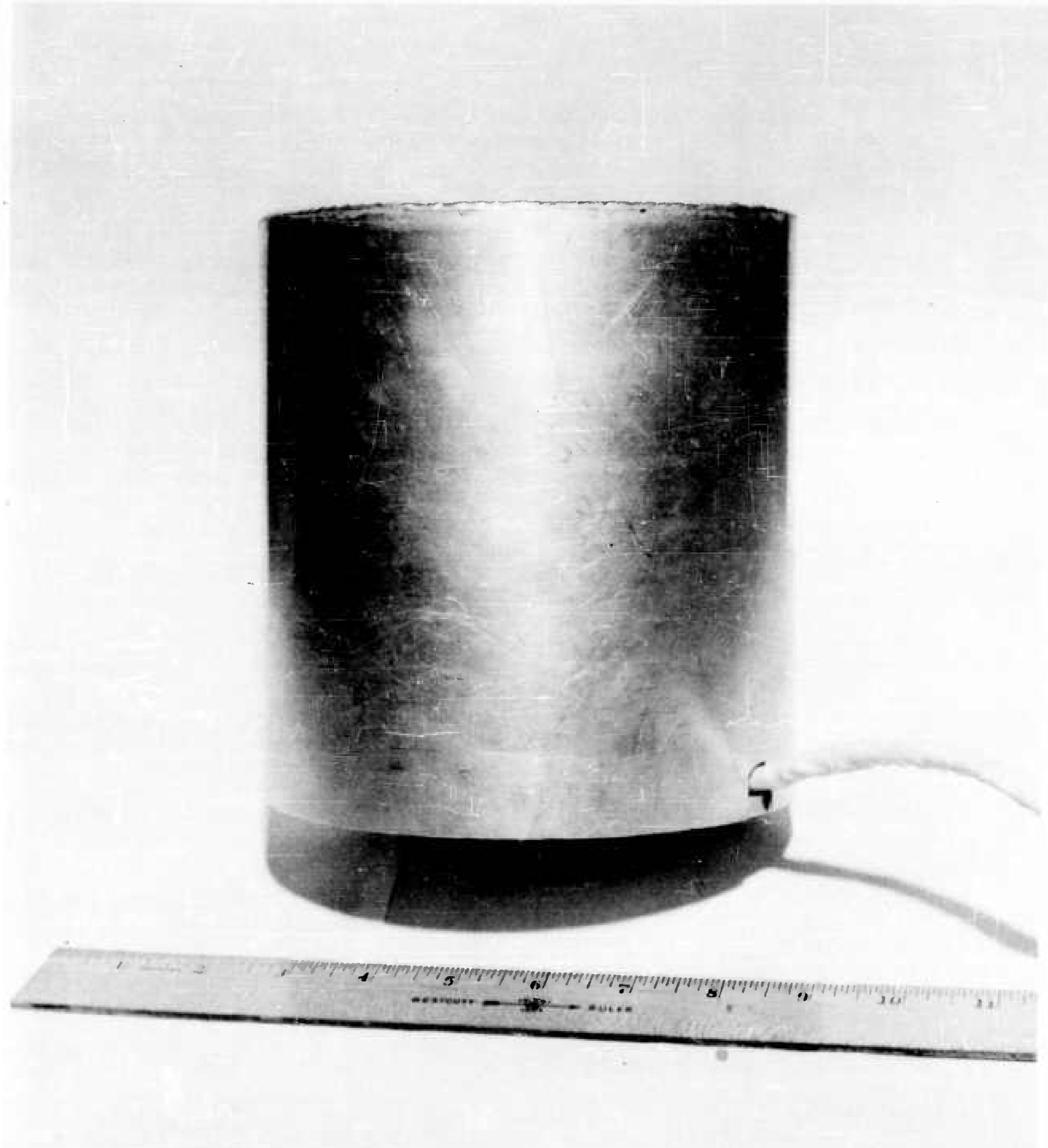


FIGURE 33   TEST FIXTURE FOR MULTIPLIER PHOTOTUBES

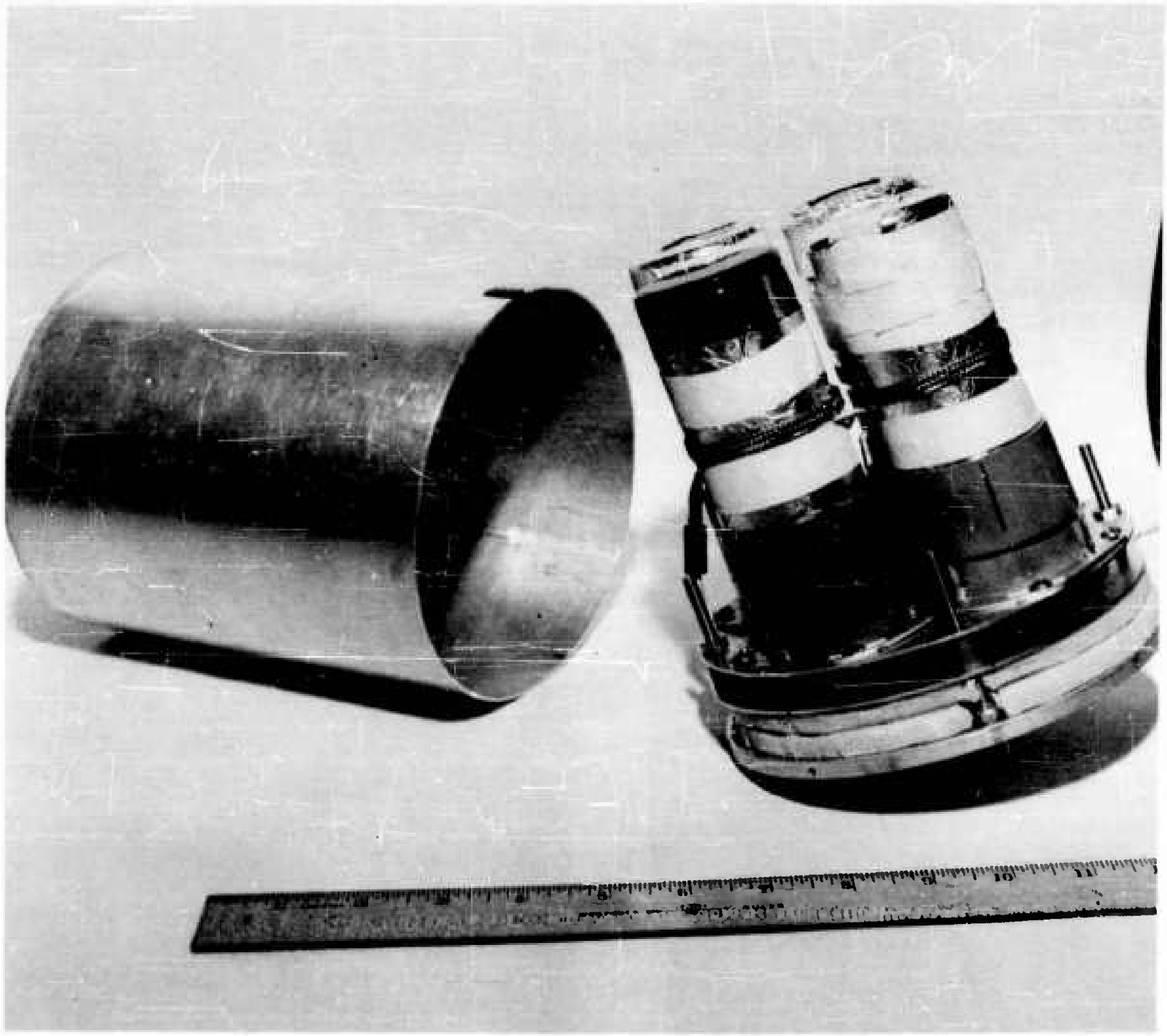


FIGURE 34 MULTIPLIER PHOTOTUBE TEST FIXTURE WITH COVER REMOVED

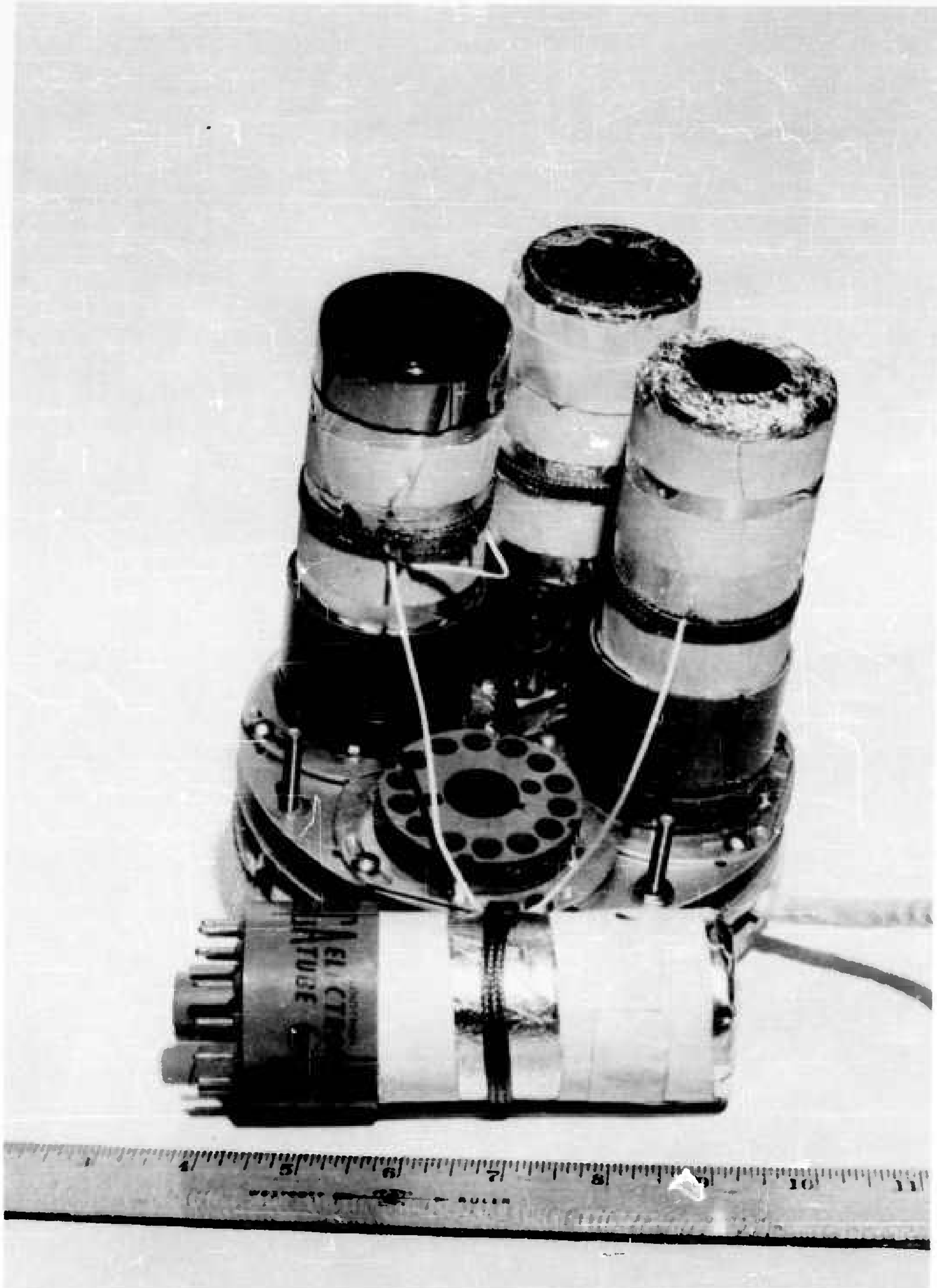


FIGURE 25 MULTIPLIER PHOTOTUBE TEST FIXTURE WITH COVER REMOVED

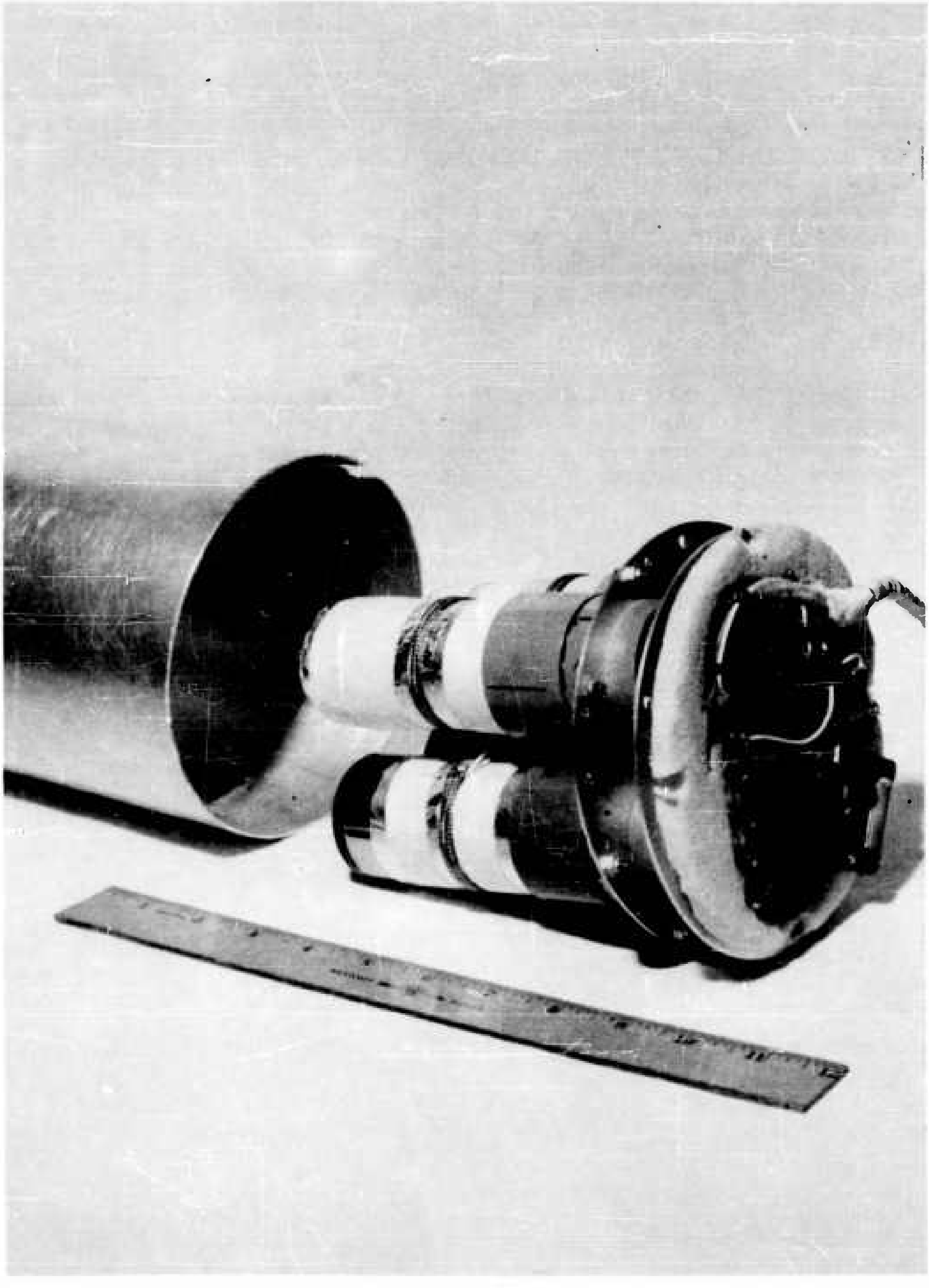


FIGURE 36 MULTIPLIER PHOTOTUBE TEST FIXTURE WITH TOP AND BOTTOM REMOVED

contact with the photomultiplier cathodes (Ref. Figures 34, 35, 36). Voltage divider circuits were located underneath the base of the photomultipliers inside the cylinder. The wiring diagrams for the RCA #5819 and DuMont 6292 multiplier phototubes are shown in Figures 37 and 38, respectively.

Prior to gamma photon exposure, stable tube operation was established as a frame of reference for testing. The masking effect which the gamma photon dose rate produced on the dark current was then evaluated. Tube characteristics were determined by plotting anode current versus voltage (0 to 150) for constant light fluxes. The same procedure was repeated with the photomultipliers in two different gamma photon dose rates. A post gamma photon exposure test was executed, repeating the same procedure, for the purpose of establishing the extent, if any, of permanent damage in photomultipliers.

4.3 Results

The effect of gamma dose rate on the dark current of both types of photomultiplier phototubes is shown in Figures 39 and 40. Even at the higher gamma dose rate the phototubes were able to sense the presence of light radiation for certain light fluxes. From the curves of Figures 39 and 40, and the fact that in most instances gamma dose rates would not exceed three orders of magnitude higher than those used, it can be concluded that certain light fluxes could be sensed even in the presence of nuclear radiation.

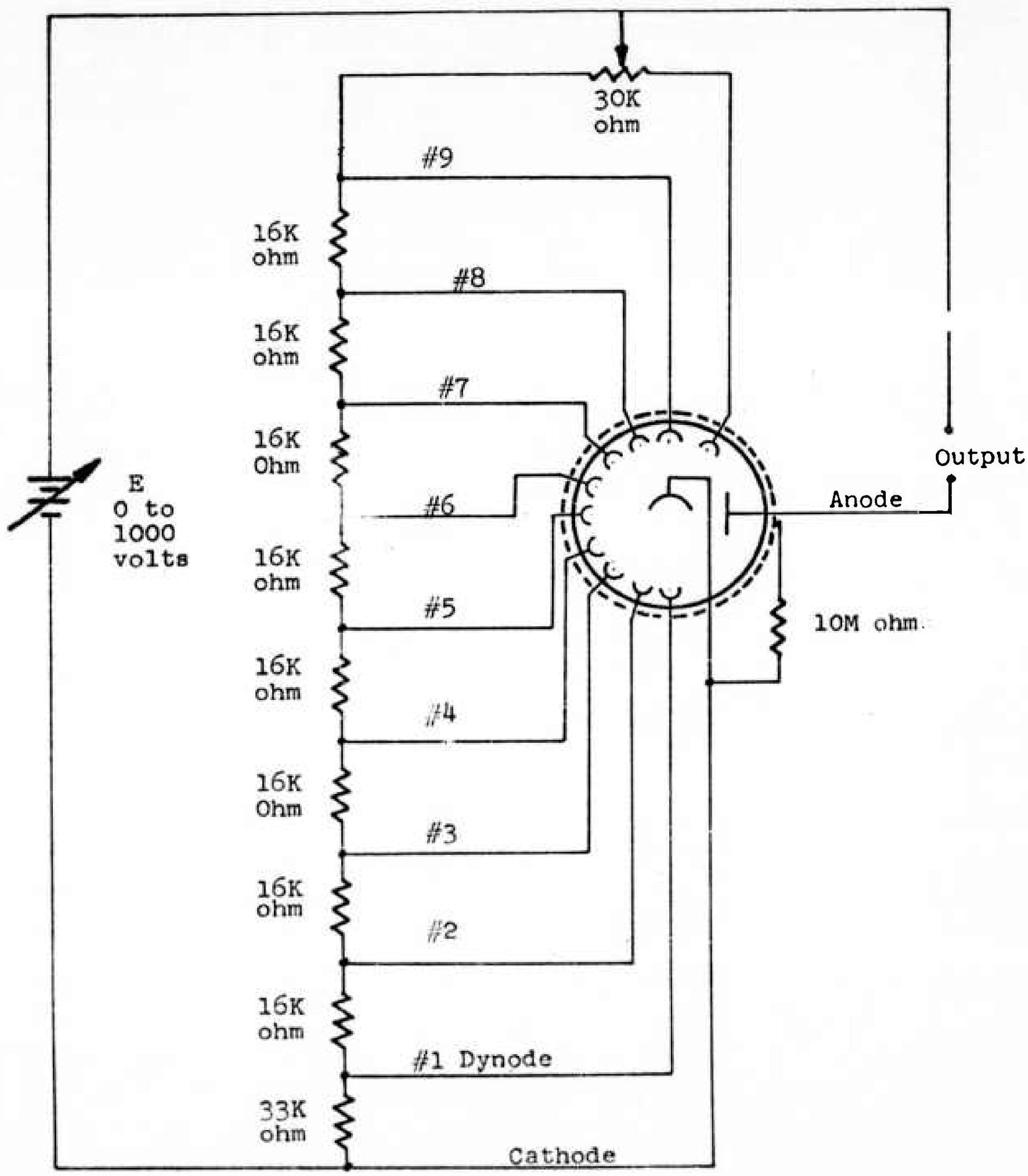


FIGURE 37 WIRING DIAGRAM FOR THE RCA 5819 MULTIPLIER PHOTOTUBE

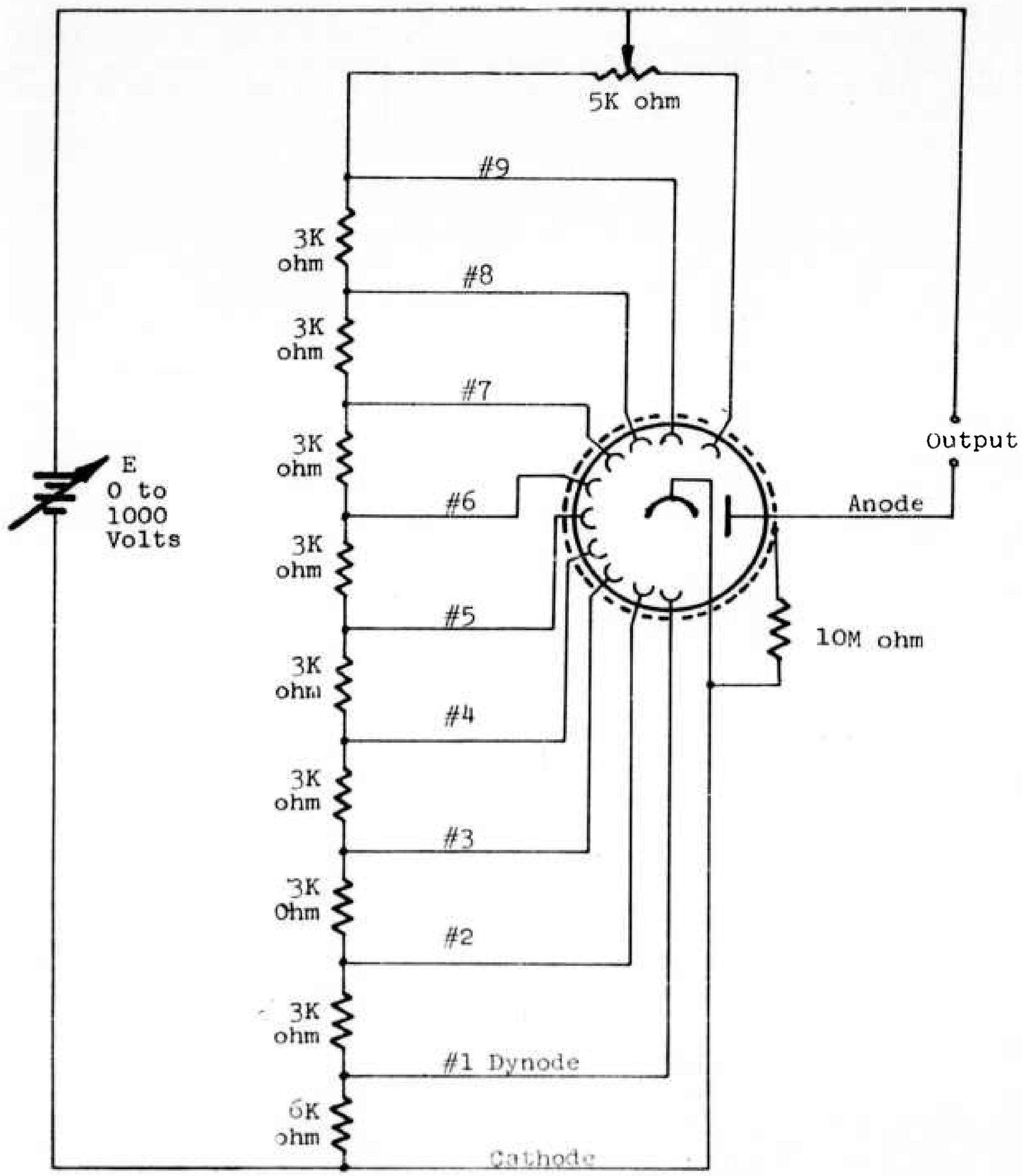


FIGURE 38 WIRING DIAGRAM FOR DUMONT 6292 MULTIPLIER PHOTOTUBE

NOTE: DYNODE NO 10 TO ANODE POTENTIAL = 70 VOLTS

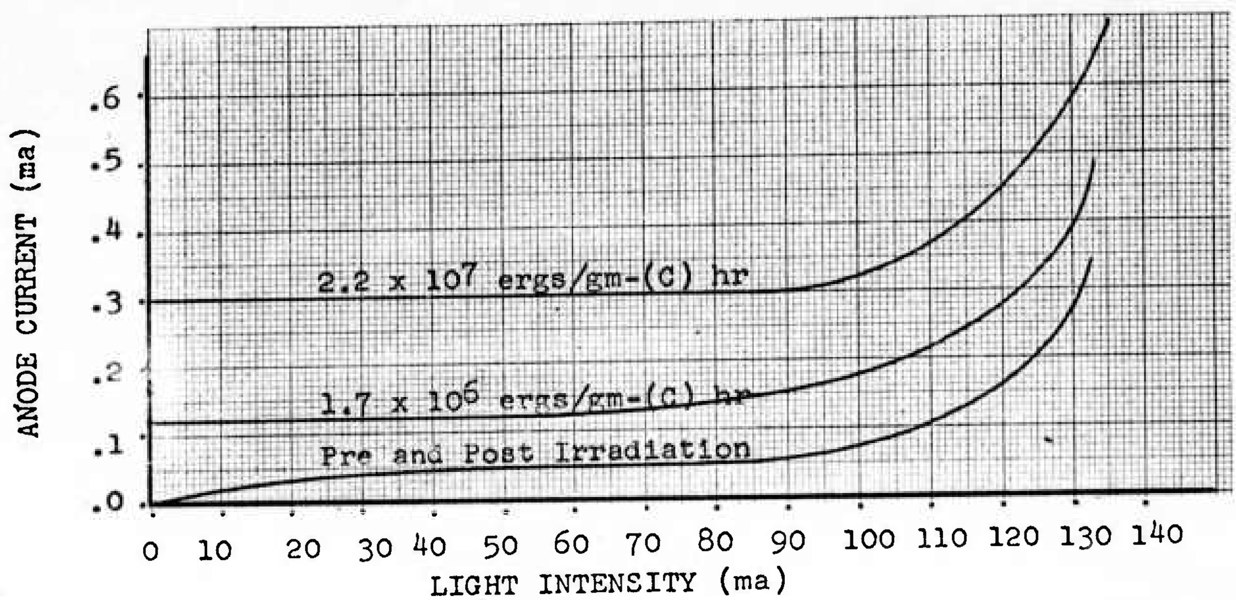


FIGURE 39 RESPONSE OF RCA 5819 MULTIPLIER PHOTOTUBE

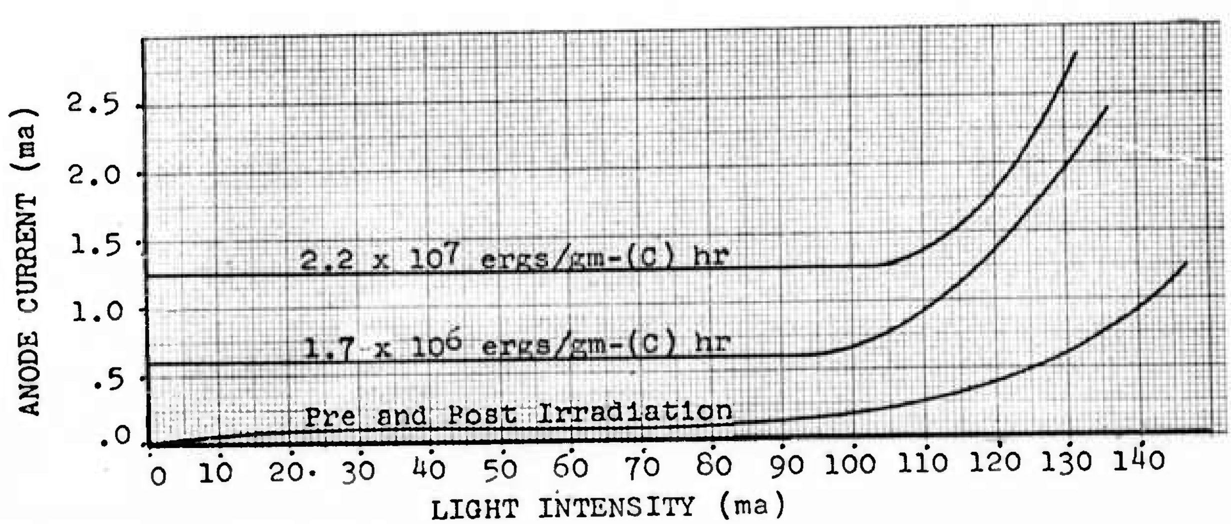


FIGURE 40 RESPONSE OF DUMONT 6292 MULTIPLIER PHOTOTUBE

V. EXPERIMENTAL XEROGRAPHIC PLATE EVALUATION

5.1 Introduction

The Image Storage, Translation, and Reproduction System (ISTAR) is a phototransmission technique for communicating image information from a reconnaissance vehicle to a remote intelligence center. Its basic concept is the conversion of energy in the visible spectrum into an electrostatic image. This conversion is realized in the conversion of light quanta into photoelectrons in a thin film of selenium. Selenium is a photosensitive material which has a high resistivity capable of sustaining a static electric charge in the absence of visible light, and capable of becoming conductive in the presence of visible light. The procedure consists of applying a uniform positive charge on the surface of the selenium plate in a dark environment; then subsequent radiant energy from a light source incident on the plate causes the selenium to become conductive, and the uniform positive charge discharges through the selenium, proportional to the amount of incident light energy. The remaining original electrostatic charge, not dissipated by the incident light energy, remains on the selenium plate for a prolonged period, for the lateral leakage of the charge is extremely small. A scanning system converts the charged pattern into a time-analog electrical signal suitable for transmission.

The purpose of this investigation was to determine if low fluxes of gamma ray photons and neutrons induced detectable gross changes in the dark resistive properties of a selenium film.

5.2 Testing

The test apparatus for evaluating the effects of nuclear radiation on the dark resistivity of a selenium film is shown in Figures 41 and 42. It consists of a 2.5 inch square by 3 inch long phenolic block (Ref. Fig. 41) built in three sections which consisted of a light window with a removeable cap, a xerographic plate and electric charging section (middle), and an electric connector recess with a removable cover (Ref. Fig. 42). A 50 micron thick amorphous selenium film identical to the photosensitive material used in commercial xerox films, 1.5 inches square deposited on an aluminum plate comprised the photosensitive plate called out in Figure 42. A loop, 3 mil mylar with a gold film a few angstroms thick, placed above the selenium plate and bearing on a gold and mylar strip which contacts the selenium was used to charge the system. A detail cross section of Figure 43 shows those features just described.

The procedure for evaluating the dark resistivity of the selenium film consisted of charging the capacitance system shown in Figure 43 with approximately 850 volts, with the light window open. A positive charge was thus stored on the selenium surface in contact with the gold

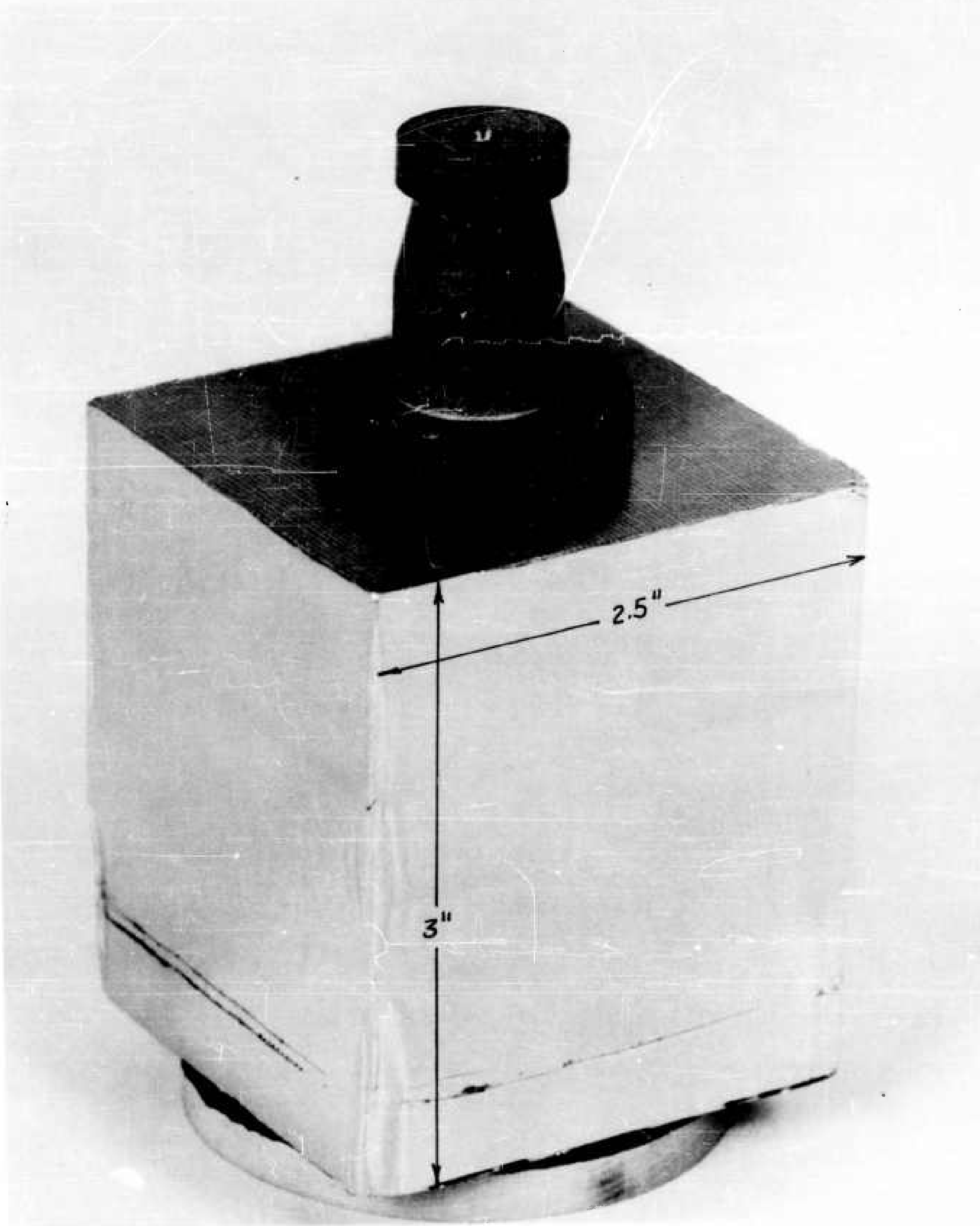


FIGURE 41 EXPERIMENTAL XEROGRAPHIC PLATE TEST APPARATUS

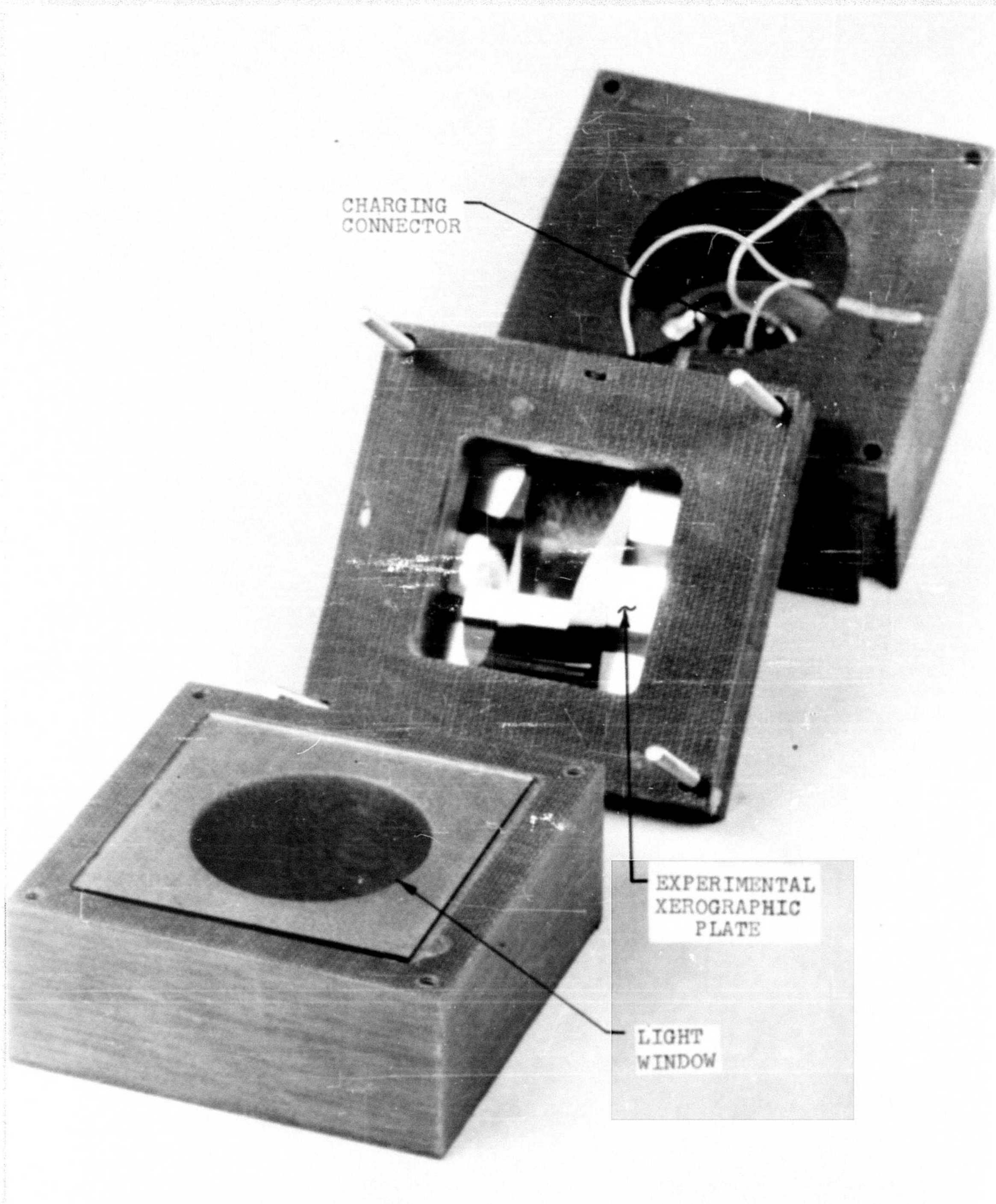


FIGURE 42 PARTIAL DISASSEMBLY OF XEROGRAPHIC PLATE APPARATUS

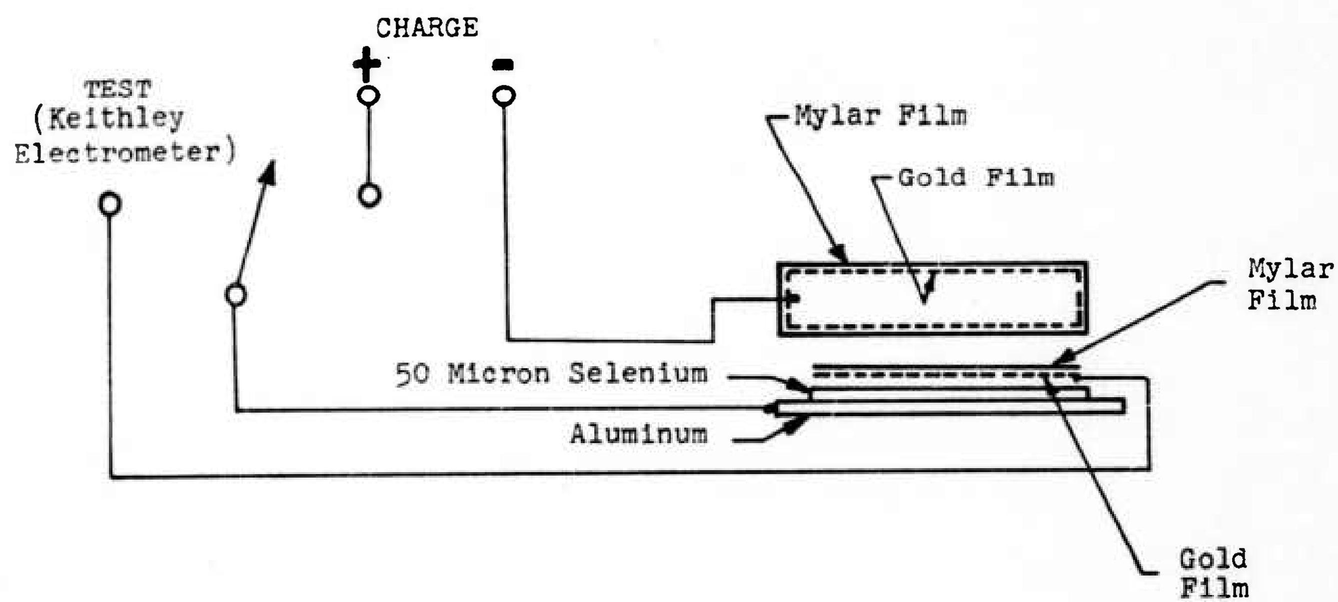


FIGURE 43 WIRING DIAGRAM OF XEROGRAPHIC PLATE TEST APPARATUS

LEGEND

Curve No.	Reactor Power Level (kw)	Exposure Time (min.)	Nuclear Dose Rate Neutrons n/cm^2-sec	Gamma ergs/gm-(C) hr
1	0	0	0	0
2	0	0.25	0	1.6×10^7
3	0	5.0	0	1.6×10^7
4	0	10.0	0	1.6×10^7
5	0	10.0	0	1.6×10^7
6	1.95	2.0	1.1×10^8	2.1×10^7
7	1.95	5.0	1.1×10^8	2.1×10^7
8	1.95	10	1.1×10^8	2.1×10^7

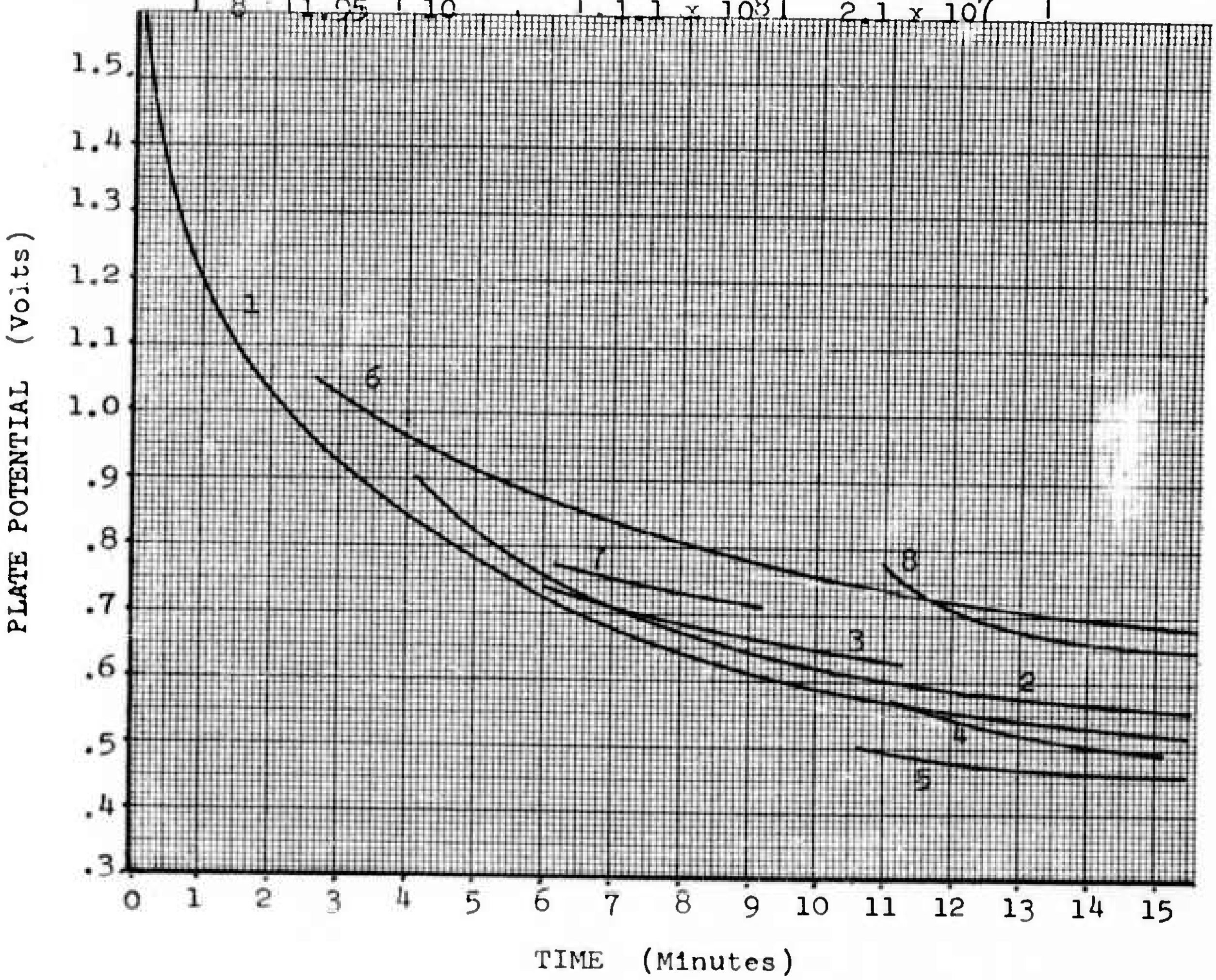


FIGURE 44 RESPONSE OF EXPERIMENTAL XEROGRAPHIC PLATE

film on mylar strip as designated in Figure 43. The potential between the aluminum plate (based of selenium) and the gold film in contact with the selenium surface was then monitored with the light window closed. Decay of potential versus time between the gold and aluminum, separated by the 50 micron film of selenium, served as a relative measure of the dark resistivity property of the selenium. This same procedure was repeated after charging and, before starting to measure voltage, the system was exposed to a gamma photon or a gamma photon plus neutron environment for a finite time. The nuclear radiation environment was achieved by placing the test fixture adjacent to General Dynamics-Fort Worth 3 megawatt reactor using a pneumatic access tube arrangement. Exposure was conducted with the reactor at 0 and 1.95 Kw power levels. At 0 Kw reactor power level a residual gamma dose rate of 1.6×10^7 ergs/gm-(C) hr existed in the test position. With the reactor at 1.95 Kw reactor power the test position dose rate was 2.1×10^7 ergs/gm-(C) hr and 1.1×10^8 n/cm^2-sec. Qualitatively, the modes of nuclear radiation interaction with selenium consist of:

(a) Gamma Photons

(1) photoelectric effect
(2) Compton scattering
(3) pair production

(b) Neutrons

(1) (n, γ) reaction (thermal cross section = 11.8b)
(2) scattering

Resulting detectable gross effects of the interactions described above on the resistivity of selenium depend upon energy spectrum of the gamma photons and neutrons, geometry of test, sensitivity of measurements, and other undetermined factors. Analytical predictions of these affects is beyond the state of the art at this time and hence experimental determinations are required.

5.3 Results

There were no distinguishable differences in dark resistivity of the selenium film when the nuclear radiation environment of 2.1×10^7 ergs/gm-(C) hr and 1.1×10^8 n_f/cm^2-sec was introduced. Variations in potential difference as a function of time are considered to be smaller than expected repeatability variations. It was concluded that the nuclear reactions occurring on the atomic level were so few in number; due to extremely small selenium sample, small flux values, and energy spectrum distribution of nuclear particles and energy; that the testing apparatus was insensitive to the gross resistivity changes which existed.

VI. SUMMARY

Conclusions pertinent to each component treated in this report are included in their respective sections. A list of all equipment irradiated, with a page index, is listed in Table 13. A brief summary of nuclear radiation exposure and results is presented in Table 14. In general, this irradiation demonstrated that presently available telemetry equipment can be radiation hardened, with only minor modifications, to substantially extend successful operation time in a nuclear radiation environment. More detailed material substitution and simple circuit redesign are clearly indicated as possible means of further extending operation of the telemetry system into a more severe nuclear radiation environment. Transmitter carrier frequency instability resulting from nuclear degradation of the quartz crystal controlled oscillator stage points out the need for additional analysis of typical oscillator circuit parameters to define:

(a) Quantitatively, to what degree are the individual active and passive circuit elements altered due to nuclear degradation.

(b) What relationship does active integration in a dynamic electronic circuit have on degradation of the element.

(c) Establish relationship of overall gross changes in oscillator circuit output parameters with individual elements.

(d) Investigate possible combinations of individual electronic element degradation which could occur within the overall operating limits of the oscillator circuit.

(e) For the typical oscillator circuit under consideration, specify element tolerances which realistically extend stable operation based upon circuit parameter degradation conpensation.

(f) Build test oscillator circuits in statistical quantities to test basic nuclear radiation degradation assumptions.

(g) From these tests determine if the quantitative degradation data used in original analysis was complete or accurate enough. In some cases actual quantitative data may not exist.

Output power failure of both the FM/FM and PM/FM transmitters was the result of non-compensating nuclear radiation induced element changes in all stages which resulted in a gradual decrease in output power.

EQUIPMENT TESTED

TABLE 13

DESCRIPTION	VENDOR	MODEL	SERIAL NUMBER	TEST FACILITY	REMARKS
230 Mc FM/FM Telemetering Transmitter	Telechrome	1472A2	590	East Pallet Convair's G T R	Radiation Hardened (Ref. Table VII)
230 Mc PM/FM Telemetering Transmitter	Bendix	TXV-13	B-1406	East Pallet Convair's G T R	Radiation Hardened (Ref. Table IX)
Mixer-Amplifier (Miniature)	Vector	S-80	1288	East Pallet Convair's G T R	Radiation Hardened (Ref. Table VI)
10.5 Kc Subcarrier Voltage Controlled Oscillator	Vector	S-81B	672	East Pallet Convair's G T R	Radiation Hardened (Ref. Table I)
14.5 Kc Subcarrier Voltage Controlled Oscillator	Vector	S-81B	1156	East Pallet Convair's G T R	Radiation Hardened (Ref. Table I)
Pressure Transducer (Potentiometer Type) 0 to 15 PSIG Range	Giannini	451224-G-1.5-95	38	East Pallet Convair's G T R	Designed for operation in Nuclear Radiation Environment
Pressure Transducer (Potentiometer Type) 0 to 30 PSIG Range	Giannini	451218	3234	East Pallet Convair's G T R	Designed for operation in Nuclear Radiation Environment
Pressure Transducer (Potentiometer Type) 0 to 1500 PSIG Range	Giannini	46119Y	1421	East Pallet Convair's G T R	Designed for operation in Nuclear Radiation Environment

TABLE 13 (Continued)

DESCRIPTION	VENDOR	MODEL	SERIAL NUMBER	TEST FACILITY	REMARKS
Pressure Transducer (Potentiometer Type) 0 to 4000 PSID Range	Giannini	46155-H-D	3644	East Pallet Convair's G T R	Standard off-the-shelf equipment
Pressure Transducer (Potentiometer Type) 0 to 150 PSIA Range	Trans-Sonic	2115	11	East Pallet Convair's G T R	Standard off-the-shelf equipment
Pressure Transducer (Potentiometer Type) 0 to 4000 PSID Range	Bourns	70624	2421	East Pallet Convair's G T R	Standard off-the-shelf equipment
Angular Position Transducer (Potentiometer Type)	Markite	3108		East Pallet Convair's G T R	Standard off-the-shelf equipment
Angular Position Transducer (Potentiometer Type)	Fairchild	747E		East Pallet Convair's G T R	Standard off-the-shelf equipment
Photosensitive Amorphus Selenium Detector	Experimental Xerographic Plates from Xero Corp.	-	-	Rabbit Tube in Convair's G T R	Test equipment designed by Chance Vought using an experimental xerographic plate (Selenium
Light Sensitive Detector	Multiplier Phototube DuMont R. C. A.	-	-	3000 curie Gamma source at Convair	Test equipment designed by Chance Vought using a light source and multiplier phototubes

TABLE 14

SUMMARY OF NUCLEAR RADIATION TEST

COMPONENT & -RESULTS	NUCLEAR RADIATION EXPOSURE NEUTRONS n_f/cm^2	GAMMA ergs/gm-(C)
Telechrome Model 1472A FM/FM Telemetering Transmitter	3.0×10^{16}	1.1×10^{11}
-0.01% carrier frequency deviation	1.0×10^{14}	3.7×10^{8}
-100% output power	6.0×10^{15}	2.0×10^{10}
Bendix Model TXV-13 PM/FM Telemetering Transmitter	3.0×10^{16}	7.5×10^{10}
-0.004% carrier frequency deviation	3.0×10^{16}	7.5×10^{10}
-100% output power	3.0×10^{14}	8.0×10^{8}
Vector Model S-81B Mixer Amplifier	2.8×10^{16}	7.6×10^{10}
Vector Model S-81B 10.5 Kc Subcarrier Voltage Controlled Oscillator	3.1×10^{16}	9.6×10^{10}
a. dc amplifier -0% output voltage	1.9×10^{16}	5.7×10^{10}
b. Multivibrator -0% output voltage	5.0×10^{14}	1.5×10^{9}
c. Low pass filter -0% output voltage	5.0×10^{14}	1.5×10^{9}
Vector Model S-81B 14.5 Kc Subcarrier Voltage Controlled Oscillator	2.8×10^{16}	8.0×10^{10}
a. dc amplifier -0% output voltage	1.0×10^{16}	2.9×10^{10}
b. Multivibrator -0% output voltage	4.0×10^{14}	1.3×10^{9}
c. Low pass filter -0% output voltage	4.0×10^{14}	1.3×10^{9}
Giannini Pressure Transducer (Potentiometer Type) 0 to 4000 PSID Range	5.1×10^{15}	2.4×10^{10}
- $\not<$ 5% output voltage deviation	1.8×10^{15}	8.5×10^{9}
Giannini Pressure Transducer (Potentiometer Type) 0 to 30 PSIG Range	7.2×10^{15}	2.9×10^{10}
-100% output voltage deviation due to unknown causes	7.2×10^{15}	2.9×10^{10}

TABLE 14 (Continued)

COMPONENT & -RESULTS	NUCLEAR RADIATION EXPOSURE	
	NEUTRONS n_f/cm^2	GAMMA ergs/gm-(C)
Giannini Pressure Transducer (Potentiometer Type) 0 to 15 PSIG Range - Failure not due to irradiation	7.25×10^{15}	2.9×10^{10}
Giannini Pressure Transducer (Potentiometer Type) 0 to 1500 PSIG Range -1.8% Maximum deviation	6.7×10^{15}	2.3×10^{10}
Trans-Sonic Pressure Transducer (Potentiometer Type) 0 to 150 PSIA - did not fail	6.7×10^{15}	2.3×10^{10}
Bourns Pressure Transducer (Potentiometer Type) 0 to 4000 PSID Range - did not fail	5.4×10^{15}	2.1×10^{10}
Markite Angular Position Transducer (Potentiometer Type) - failed	7.6×10^{15}	3.1×10^{10}
Fairchild Angular Position Transducer (Potentiometer Type) -failed	7.6×10^{15}	3.1×10^{10}
	NUCLEAR RADIATION EXPSOURE RATE	
	NEUTRONS n_f/cm^2 sec	GAMMA ergs/gm-(C)hr
Photosensitive Amorphus Selenium Detector No gross changes in dark resistivity detected	1.1×10^{8}	2.1×10^{7}
Light Sensitive Detector Light pulse detectable above gamma induced dark current	-	2.2×10^{7}

APPENDIX I
DOSIMETRY

1.0 The Ground Test Reactor (GTR)

The telemetering system transducer, servo actuator package, and PM generator were irradiated in the east position of the three megawatt water moderated, enriched uranium 235 GTR at General Dynamics, Fort Worth during the period of September 18 through 21, 1961, for a total exposure of approximately 81 hours or 237 Mw hours. The reactor operation log is presented in Table 15.

TABLE 15

GTR REACTOR OPERATION LOG
(RUN NO. 6)

DATE (Sept. 1961)	TIME (hrs)	REACTOR POWER (Mw)	DESCRIPTION
18	0451	0.05	Went to power
18	0651	3.0	Increased power
18	1045	0.0	Reactor shut down
18	1136	3.0	Went to power
19	1326	0.0	Retracted reactor out of closet
19	1452	3.0	Returned reactor to closet position
19	1501	0.0	Reactor shut down
19	1531	3.0	Went to power
21	1004	0.0	Retracted reactor out of closet
21	1141	3.0	Returned reactor to closet position
21	1258	0.0	Reactor shut down
21	1324	3.0	Went to power
21	1925	0.0	Terminated test

Dosimetry packets were used to monitor the nuclear radiation exposure of each component and consisted of nitrous oxide detectors for gammas; aluminum foils, bare and cadmium-covered cobalt foils and sulphur foils for neutron fluxes. A description of the neutron-detector characteristics is contained in Table 16.

TABLE 16

DESCRIPTION OF NEUTRON DETECTORS

Foil Type	Code	Size	Energy Range	Reaction
Cobalt	OA, OG	1 cm^2 x 0.00[illegible]"	E 0.4[illegible] ev	$Co^{59}(n, \gamma)Co^{60}$

TABLE 16 (Continued)

Foil Type	Code	Size	Energy Range	Reaction
Sulfur	SX	0.75" dia. x 0.26"	E 2.9 Mev	$S^{32}(n,p)\ P^{32}$
Aluminum	LF	$1cm^2$ x 0.010"	E 8.1 Mev	$Al^{27}(n,\alpha)Na^{24}$

Twenty-four dosimetry packets were mounted on the test pallet at different locations. The packet numbers and locations are listed in Table IIIA; all directions are looking toward the east pallet from the reactor closet, except for the transducer system which is described as if looking from the south to the north.

TABLE 17

LOCATION AND IDENTIFICATION NUMBERS OF DOSIMETRY PACKETS

Packet No.	Location
1	2 inches above 14.5 kc SCO.
2	3 inches to left at top edge of Bendix transmitter
3	1 inch to right of mixer
4	right edge of Telechrome transmitter
5	1 inch above Telechrome transmitter
6	1 inch to left of Bendix transmitter
7	behind and midway between 14.5 kc SCO and mixer
8	behind Bendix transmitter
9	left side 10.5 kc SCO
10	behind center of Telechrome transmitter
11	2 inches above actuator output shaft
12	above actuator drive motor
13	2 inches below actuator drive motor
14	2 inches below actuator shaft
15	top of generator drive motor
16	top of generator
17	2 inches below base of cathode follower
18	2 inches right of stepping switch
19	behind Trans-Sonic Pressure Transducer #215
20	behind Giannini Pressure Transducer #46155H-4-10
21	1.5 inches to left of Giannini Pressure Transducer #1421
22	2 inches to right of Giannini Pressure Transducer #451218
23	1 inch above Markite pot
24	1 inch above Fairchild pot

These locations are also shown on Figures 45, 46, 47 as actual physical locations on east pallet.

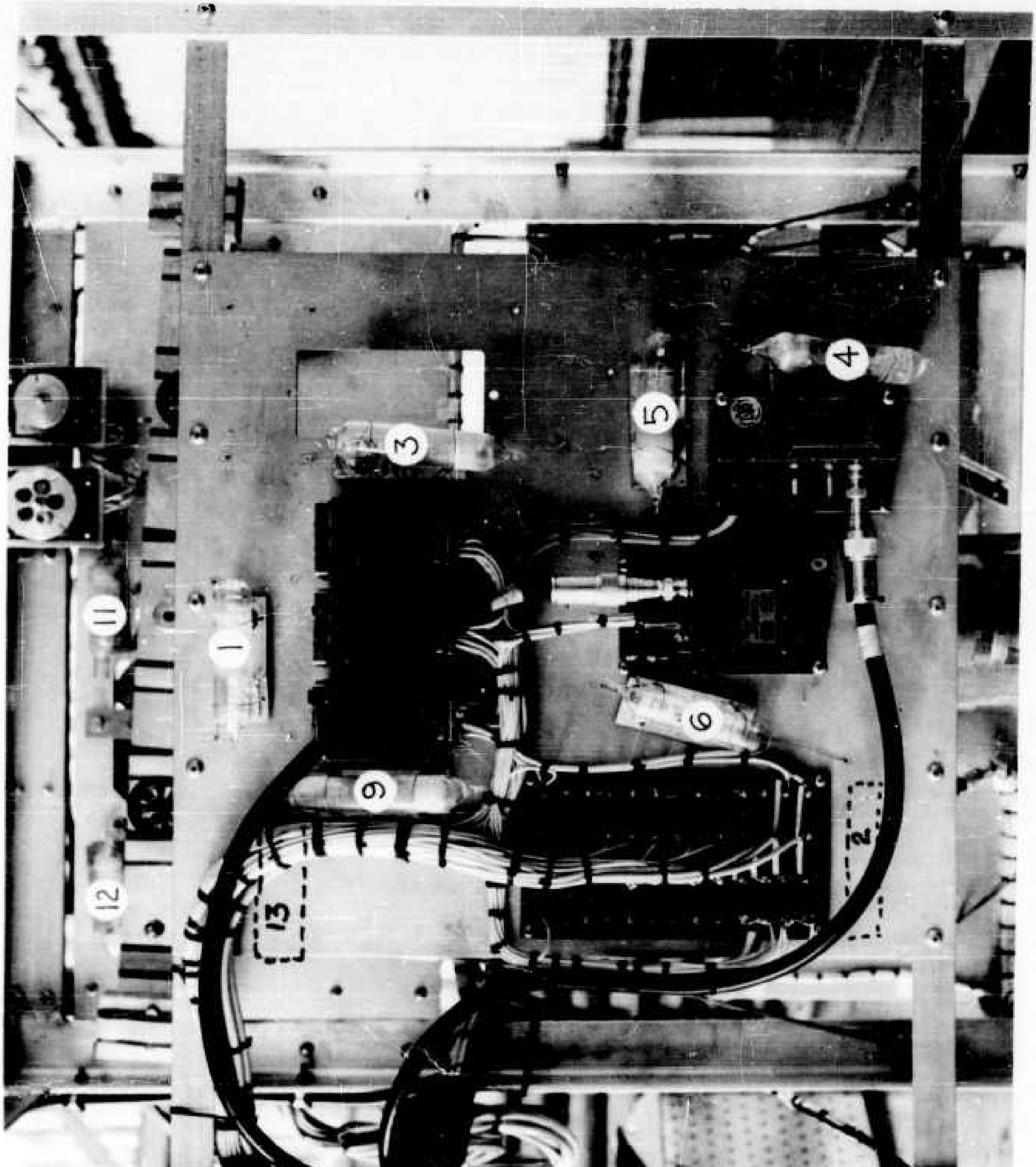


FIGURE 4.5 DOSIMETRY PACKET LOCATIONS ON EAST PALLET OF G.T.R.

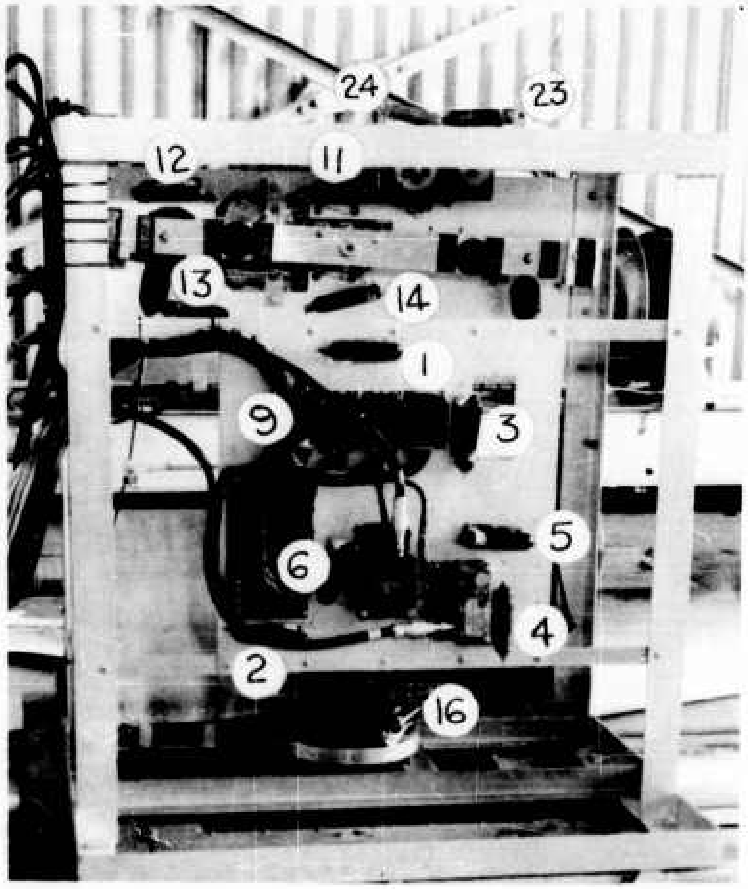


FIGURE 46 DOSIMETRY PACKET LOCATIONS ON EAST PALLET OF G.T.R.

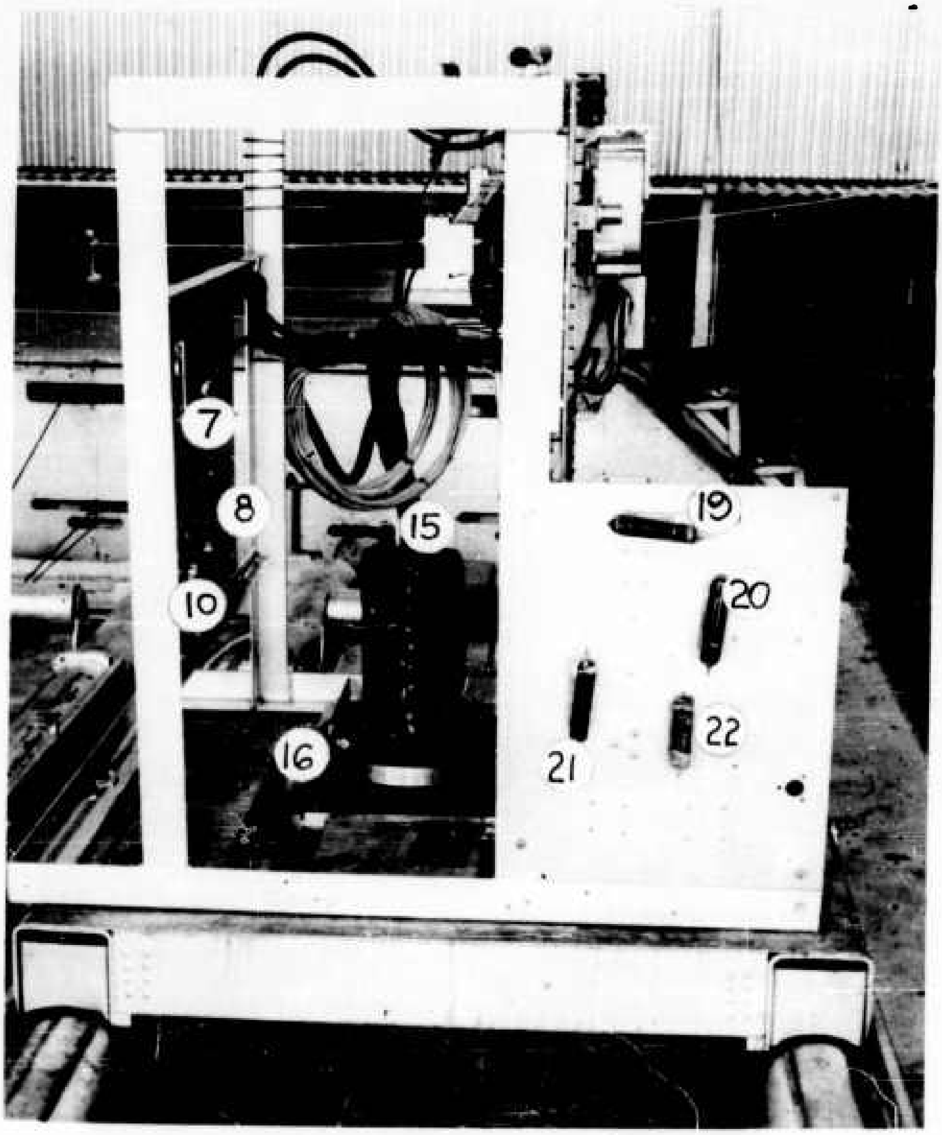


FIGURE 47 DOSIMETRY PACKET LOCATIONS ON EAST PALLET OF G.T.R.

The dosimetry for this test was furnished by General Dynamics-Fort Worth. The results of the dosimetry measurements are reported in Table 18. The fast neutron fluxes for neutrons with energies greater than one million electron volts were calculated from the sulfur data by the relationship

$$\phi_{1\ Mev} = 2.84\ \phi_{2.9\ Mev}$$

which is applicable for the G.T.R spectrum (Ref. Fig. 48).

TABLE 18

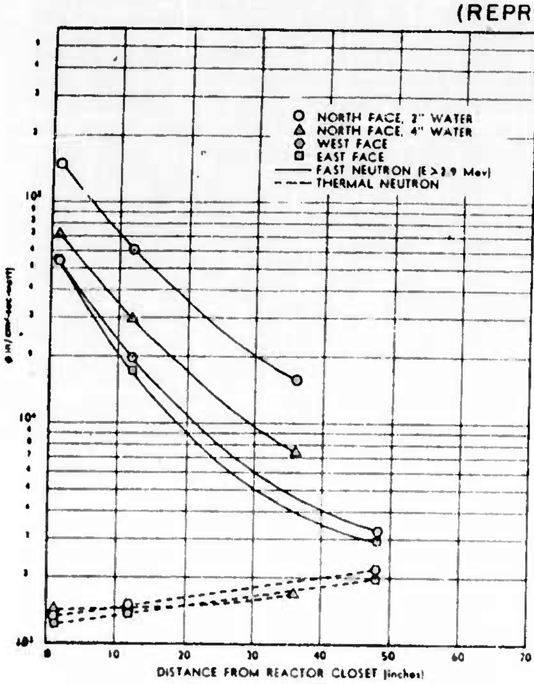
RESULTS OF NEUTRON AND GAMMA DOSIMETRY MEASUREMENTS

PACKET NUMBER	INTEGRATED NEUTRON FLUXES, (n/cm^2)			GAMMA DOSE ergs/gm-(C)
	$E_n < 0.48$ ev	$E_n > 1.0$ Mev*	$E_n > 2.9$ Mev	
1	5.74 (14)**	2.93 (16)	1.04 (16)	8.2 (10)
2	5.63 (14)	2.96 (16)	1.05 (16)	9.2 (10)
3	6.43 (14)	3.19 (16)	1.13 (16)	9.6 (10)
4	5.49 (14)	3.15 (16)	1.12 (16)	1.5 (11)
5	5.49 (14)	3.61 (16)	1.28 (16)	1.1 (11)
6	5.10 (14)	3.58 (16)	1.27 (16)	8.9 (10)
7	8.26 (14)	2.76 (16)	9.78 (15)	7.9 (10)
8	1.06 (15)	2.93 (16)	1.04 (16)	7.5 (10)
9	2.15 (14)	3.10 (16)	1.10 (16)	9.6 (10)
10	9.33 (14)	3.02 (15)	1.07 (16)	1.1 (11)
11	8.16 (14)	8.78 (15)	3.11 (15)	3.0 (10)
12	7.87 (14)	7.84 (15)	2.78 (15)	2.6 (10)
13	9.30 (14)	9.67 (16)	3.43 (15)	3.2 (10)
14	8.99 (14)	1.07 (16)	3.80 (15)	3.8 (10)
15	7.08 (14)	1.63 (16)	5.77 (15)	5.1 (10)
16	4.86 (14)	1.65 (16)	5.84 (15)	6.0 (10)
17	1.17 (15)	6.57 (15)	2.33 (15)	2.1 (10)
18	1.24 (15)	5.47 (15)	1.94 (15)	1.7 (10)
19	7.23 (14)	6.68 (15)	2.37 (15)	2.3 (10)
20	8.22 (14)	5.16 (15)	1.83 (15)	2.4 (10)
21	6.64 (14)	7.20 (15)	2.55 (15)	2.9 (10)
22	8.17 (14)	5.42 (15)	1.92 (15)	2.1 (10)
23	8.77 (14)	7.76 (15)	2.75 (15)	3.1 (10)
24	8.41 (14)	7.50 (15)	2.66 (15)	3.2 (10)

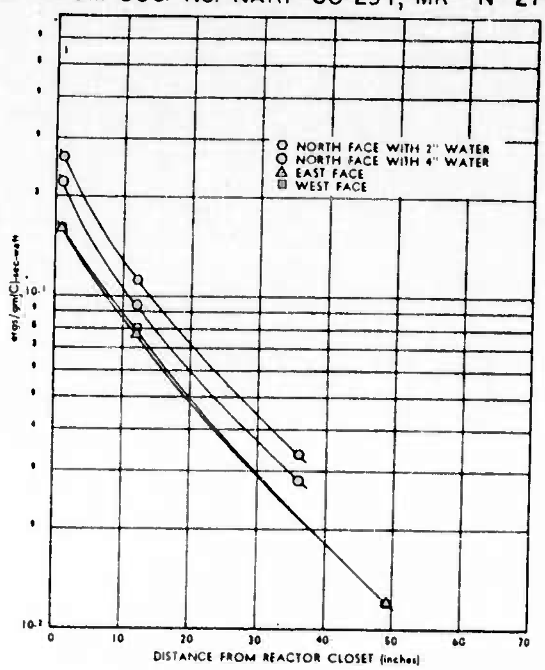
* This column was obtained from the reported sulfur data and $\Phi_{1\ Mev} = 2.84\,\Phi_{2.9\ Mev}$

** Where (x) denotes 10^x

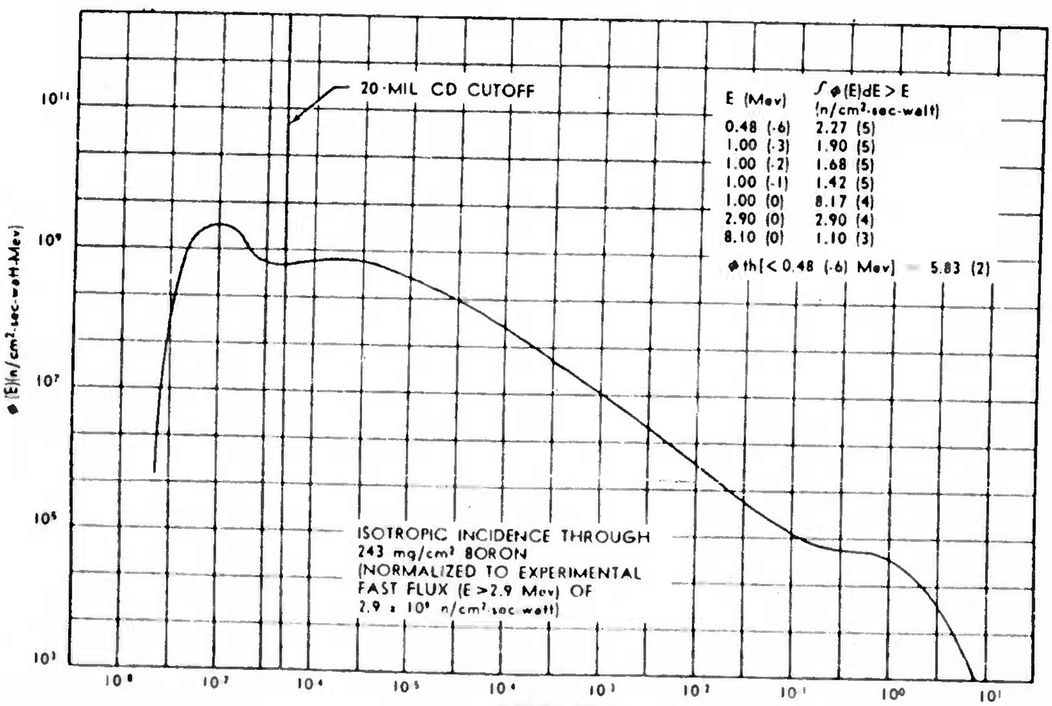
(REPRODUCED FROM DOC. NO. NARF-60-23T, MR - N-270)



AVERAGE NEUTRON FLUXES ON REACTOR CENTERLINES



AVERAGE GAMMA VALUES ON REACTOR CENTERLINES



ANALYTIC GTR SPECTRA, BORAL ATTENUATED

FIGURE 48

APPENDIX II

MINIATURE SUBCARRIER OSCILLATOR
VECTOR TYPE S-81B

SPECIFICATIONS*

PHYSICAL CHARACTERISTICS:

SIZE:	1.875 inches by 1.422 inches by 2.188 inches
WEIGHT:	6.5 ounces

PERFORMANCE CHARACTERISTICS:

POWER REQUIREMENTS:	Plate: 150 volts at 5 ma Filament: 6.3 volts dc at 600 ma
INPUT IMPEDANCE:	1.0 megohm ± 20%
OUTPUT IMPEDANCE:	47 K ohms
OUTPUT VOLTAGE:	2.5 volts rms minimum
MODULATION SENSITIVITY:	0 to 5 volts dc for 7½ % deviation
STABILITY:	Filament Voltage: A change of ± 10% will vary the center frequency less than ± 2% Plate Voltage: A change of ± 3% will vary the center frequency less than ± 2%
DRIFT:	Less than ± 2% of design bandwidth for a period of 8 hours at room temperature
DISTORTION:	At center frequency, the total harmonic distortion of output signal is less than 0.75%
LINEARITY:	Less 0.75% of design bandwidth from best straight line

ENVIROMENTAL CHARACTERISTICS:

ACCELERATION:	50g
ALTITUDE:	100,000 ft.
HUMIDITY:	95% at 50°C
SHOCK:	60g
TEMPERATURE:	-70°C to 115°C
VIBRATION:	55 to 2000 CPS and 10g in each major axis

*Vector Mfg. Co., Inc. TECHNICAL BULLETIN NO. B-2

APPENDIX III

MIXER AMPLIFIER, MINIATURE
VECTOR TYPE A-80

SPECIFICATIONS*

PHYSICAL CHARACTERISTICS:

SIZE:	Overall dimensions, 1.875 in. by 1.422 in. by 2.188 inches
WEIGHT:	6.5 ounces

PERFORMANCE CHARACTERISTICS:

POWER REQUIREMENTS:	Plate: 150 volts dc at 15 ma Filament: 6.3 volts dc at 600 ma.
OUTPUT IMPEDANCE:	Cathode follower output
HARMONIC DISTORTION:	Less than 5%
FREQUENCY RESPONSE:	Less than 0.5 db from 100 cps to 100 Kcps
GAIN:	Adjustable to approximately 20X 10 volts rms maximum output

ENVIROMENTAL CHARACTERISTICS:

ACCELERATION:	50 g
SHOCK:	50 g
VIBRATION:	55 to 2,000 cps and 10g in each major axis
TEMPERATURE:	-70°C to + 115°C

*Vector Mfg. Co., Inc., TECHNICAL BULLETIN NO. K-2

APPENDIX IV

FM/FM SUBMINIATURE TELEMETERING TRANSMITTER

TELECHROME MODEL 1472-A2

SPECIFICATIONS*

PHYSICAL CHARACTERISTICS:

SIZE:	4.00 inches long, 2.75 inches wide, 1.50 inches high
WEIGHT:	11 ounces

PERFORMANCE CHARACTERISTICS:

POWER REQUIREMENTS:	200 volts dc ± 5% at 60 ma 6.5 volts dc ± 3% at 0.8 amp 26 volts dc ± 3% at .2 amp
FREQUENCY:	230 Mc
POWER OUTPUT:	2 watts minimum into a 50 ohm non-reactive load
FREQUENCY STABILITY:	Carrier frequency stable within ± 0.01%
MODULATION LINEARITY:	Frequency deviation proportional to signal amplitude with a linearity of 5% or better, from 0-3 volts peak to peak input
FREQUENCY RESPONSE:	Flat within ± 3 db from 100 cps through 80,000 cps
FREQUENCY DEVIATION:	± 150 Kc maximum
DEVIATION SENSITIVITY:	2.75 volts peak to peak from 100 cps through 80,000 cps for ± 75 Kc deviation at output frequency
DISTORTION:	Less than 3.0% for 1.5Kc sine wave modulation

ENVIRONMENTAL CHARACTERISTICS:

ACCELERATION:	12g
SHOCK:	30g
TEMPERATURE:	-55°C to 100°C
VIBRATION:	55 to 2,000 cps and 10 g in each major axis

*Telechrome Mfg. Co., TECHNICAL BULLETIN

APPENDIX V

PM/FM TELEMETERING TRANSMITTER
BENDIX-PACIFIC MODEL TXV-13

SPECIFICATIONS*

PHYSICAL CHARACTERISTICS:	
SIZE:	1.63 inches high by 3.03 inches wide by 4.58 inches long
WEIGHT:	1.1 lb
PERFORMANCE CHARACTERISTICS:	
POWER REQUIREMENTS:	Heater supply 6.3 volts dc at 1.2 amp B+ voltage of 180 volts dc B+ current of 85 ma nominal
FREQUENCY:	230 Mc
POWER OUTPUT:	1.8 watts minimum with rated supply voltages
FREQUENCY STABILITY:	Carrier frequency stable within ±.01%
DEVIATION SENSITIVITY:	Modulation index 12.5 per volt +20%, - 10%
DISTORTION:	1.0% maximum theoretical distortion for a modulation index of 2. Actual demodulator distortion is less than 2%
OUTPUT (RF) LOAD IMPEDANCE:	50.0 ohms nominal
OUTPUT SPURIOUS:	At least 50 db below carrier in the HF, VHF, and UHF spectrums
ENVIRONMENTAL CHARACTERISTICS:	
CONSTANT ACCELERATION:	Constant acceleration to 60g in any plane produces less than 1% of bandwidth variation
SHOCK:	With a 60g acceleration applied abruptly and sustained for 25 milliseconds, in any plane, the transient noise peak produced on a typical subcarrier output is less than 10% of bandwidth
TEMPERATURE:	For a temperature change from -40°F to 185°F the carrier frequency remains constant within .01%
VARIATION:	Less than 2.0 Kc peak carrier frequency deviation produced by vibration up to 10g at frequencies up to 1000 cps in any plane

* Bendix-Pacific Technical Bulletin dated January 6, 1958

APPENDIX VI

0 TO 15 PSIG GIANNINI MODEL 451224
PRESSURE TRANSDUCER

SPECIFICATIONS*

POTENTIOMETER RESISTANCE:	The potentiometer resistance shall be 2000 to 10,000 ohms (±5%).
WEIGHT:	The maximum weight of the transducer shall be 12 oz.
LINEARITY:	The maximum deviation in voltage ratio of the increasing calibration curve from the most favorable straight line drawn through it shall be 0.008.
RESOLUTION:	The minimum number of turns of wire on the potentiometer shall be 250.
REPEATABILITY:	The maximum difference between voltage-ratio measurements made at the same pressure under identical conditions shall be 0.005.
HYSTERESIS:	The maximum difference in voltage ratio between the increasing and decreasing calibration curves shall be 0.005.
FRICTION:	The maximum change in voltage ratio when the transducer is tapped or vibrated lightly after a pressure change shall be 0.012.
INSULATION RESISTANCE:	The minimum insulation resistance between each electrically isolated terminal and the case shall be 50 megohms when tested at 250 Vdc.
POWER RATING:	The potentiometer shall safely carry a continuous-duty load of 0.25 watts when operated within the rated temperature range.
TEMPERATURE:	The voltage ratios measured at any temperature within the range of -54°C (-65°F) to +100°C (+212°F) shall not differ from that measured at room temperature by more than 0.012.

OVERPRESSURE: Overpressure 20% in excess of full range shall not cause electrical discontinuity or a change in calibration.

* Giannini Specification S451224.01, Dated 20 September 1957

APPENDIX VII

0 TO 30 PSIG GIANNINI MODEL 451218 PRESSURE TRANSDUCER

SPECIFICATIONS*

POTENTIOMETER RESISTANCE:	The potentiometer resistance shall be available from 2000 ohms to 10,000 ohms with a tolerance of ± 5%.
WEIGHT:	The maximum weight of the transducer shall be 1 oz.
LINEARITY:	The maximum deviation in voltage ratio of the increasing calibration curve from the most favorable straight line drawn through it shall be 0.010.
REPEATABILITY:	The maximum difference in voltage ratio between any reading taken at any pressure point and any other reading taken at the same pressure under identical conditions shall be 0.005.
FRICTION:	The maximum difference in voltage ratio when the transducer is tapped after a pressure change shall be 0.012 for pressure ranges above 30 psi and 0.015 for pressure ranges below 30 psi.
INSULATION RESISTANCE:	The minimum insulation resistance between each terminal and the case shall be 50 megohms at sea level. Measurements of absolute models shall be made at 250 Vdc. Measurements of differental and gage models shall be made at 500 Vdc.
CURRENT RATING:	The potentiometer shall safely dissipate continuously 0.25 watts at + 71°C.
TEMPERATURE:	The voltage ratios measured at any temperature within the range of -54°C (-65°F) and + 85°C (+185°F) shall not differ from that measured at room temperature by more than 0.00025 VR/°C.
OVERPRESSURE:	Overpressure 20% in excess of full range shall not cause electrical discontinuity or a change in calibration.

* Giannini Specification S451218.01, Rev. D, Dated 2 December 1959

APPENDIX VIII

0 to 1500 PSIG GIANNINI MODEL 46119Y PRESSURE TRANSDUCER

SPECIFICATIONS*

POTENTIOMETER RESISTANCE:	The potentiometer shall have any specified total resistance from 1000 to 10,000 ohms, +10%, -0.
WEIGHT:	The maximum weight of the transducer shall be 9 oz.
LINEARITY:	The maximum deviation in voltage ratio of the increasing calibration curve from the most favorable straight line drawn through it shall be 0.010.
RESOLUTION:	The minimum number of turns of wire on the potentiometer shall be 150.
REPEATABILITY:	The maximum difference between voltage-ratio requirements made at the same pressure under identical conditions shall be 0.008.
HYSTERESIS:	The maximum difference in voltage ratio between the increasing and decreasing calibration curves shall be as follows: 0.010 - 0 thru 2000 psi
FRICTION:	The maximum change in voltage ratio when the transducer is tapped after a pressure change shall be 0.008.
INSULATION RESISTANCE:	The minimum resistance between each electrically isolated terminal and the case shall be 50 megohms when measured at 500 Vdc at sea level.
CURRENT RATING:	The potentiometer shall safely carry a maximum continuous-duty current of 10 milliamperes at 2000 ohms and 7 milliamperes at 5000 ohms.
TEMPERATURE:	The maximum difference between voltage-ratio measurements made at -54°C (-65°F) and +71°C (+160°F) and those made at room temperature shall be 0.020.

APPENDIX VIII (Continued)

OVERPRESSURE:	An overpressure 20% in excess of the full pressure range of the transducer shall not cause structural damage, electrical discontinunity, or a change in calibration.

* Giannini Specification S46119.12, Rev. E, Dated 15 January 1960

APPENDIX IX

0 TO 4000 PSID GIANNINI MODEL 46155-H-D PRESSURE TRANSDUCER

SPECIFICATIONS*

POTENTIOMETER RESISTANCE:	The potentiometer resistance may be any resistance from 2000 to 7500 ohms with a tolerance of ± 5.0%.
LINEARITY:	The maximum deviation in voltage ratio of the increasing calibration curve from the most favorable straight line drawn through it shall be 0.010.
RESOLUTION:	The maximum average increment of output shall be a voltage ratio of 0.007.
REPEATABILITY:	The maximum difference between voltage-ratio measurements made at the same pressure under identical conditions shall be 0.008.
HYSTERESIS:	The maximum difference in voltage ratio between the increasing and decreasing calibration curves shall not exceed the values shown in the following table: PRESSURE RANGE (psi) — HYSTERESIS (vr) 0 thru 5000 — 0.020
FRICTION:	The maximum change in voltage ratio when the transducer is tapped or vibrated lightly after a pressure change shall not exceed 0.008.
INSULATION RESISTANCE:	The minimum resistance between each electrically isolated terminal and the case shall not exceed 50 megohms when measured at 500 Vdc at sea level.
POWER RATING:	The potentiometer shall safely dissipate a continuous power of 0.5 watt. The maximum continuous-duty current rating is governed by this power rating and the potentiometer resistance.
TEMPERATURE:	The voltage ratio measured at -54°C (-65°F) shall not differ from that measured at

TEMPERATURE (Continued): room temperature by more than 0.020. The voltage ratio measured at + 149°C (+300°F) shall not differ from that measured at room temperature by more than 0.025.

OVERPRESSURE: The structural and performance characteristics of the transducer shall not be affected adversely by the application of a pressure 20% in excess of the full pressure range.

* Giannini Specification S46155.02 Rev. F, Dated 19 Jan 1960

APPENDIX X

I. INTERACTION OF NUCLEAR ENERGY WITH MATTER

1.1 Introduction

Components in the test were subjected to neutrons, gamma photons, and neutrinos emitted from a reactor. Neutrino energy can be neglected altogether because the probability of its interaction with matter is extremely small. Interaction of neutrons and gamma photons with matter are of chief concern because the probability of interaction with certain atomic nuclei is large enough to bring about physical and chemical changes on the molecular level, thus altering the functional applicability of materials.

1.2 Neutron Reactions

Neutrons are neutral sub-atomic particles recognized as one of the fundamental nuclear particles by Chadwick in 1932. Being electrically neutral, neutrons penetrate most solid bodies rather freely, moving through them by diffusion, due to the scattering effect by atomic nuclei. Neutrons interact with matter on the nuclear level by "absorption" and "scattering."

The absorption mechanism of atomic nuclei is related to the neutron kinetic energy and is usually divided into slow and fast neutron interactions. Absorption reactions are basically the capture of a neutron by an atomic nucleus, which forms a compound nucleus of the same element, with the ultimate expulsion of particles or a subdivision into two parts. The difference between fast and slow neutron absorption is the predominant decay scheme of the excited compound nucleus to the ground state.

Expulsion of a charged particle from the excited compound nucleus, formed as a result of fast neutron capture, is more probable than gamma photon emission. Hence, neutron-alpha and neutron-proton reactions of nuclei with fast neutrons having energies of 1 Mev or more, occur more readily than the neutron, gamma photon reaction.

The most common slow-neutron reaction is the radiative capture process in which the target nuclei absorbs a slow-neutron and emits a gamma photon. Other slow neutron absorption reactions involve neutron absorption by nuclei followed by either (1) the ejection of an alpha particle; (2) the ejection of a proton; (3) fission.

Neutron scattering by nuclei is a reaction in which the neutron interacts with, and transfers part or all of its energy to, the nucleus, but the neutron remains free after the process. Scattering collisions are of two types, elastic and inelastic. In an inelastic scatter process momentum is conserved, but kinetic energy is not. Part of the neutron kinetic energy is converted into internal energy of the struck nucleus. Inelastic neutron scattering is related to specific properties

of the struck nucleus and in general only occurs when the kinetic energy of the neutron is fairly large. Conservation of both energy and momentum is characterized by elastic neutron scattering. Some or all of the neutron kinetic energy appears as kinetic energy of the struck nucleus, thus reducing the neutron velocity. The amount of kinetic energy given up by the neutron is related to the scattering angle and atomic mass number of scatterer. Kinetic energy transferred to the atoms in a material is dissipated by ionization, excitation and more elastic collisions with other atoms.

1.3 Gamma Photon Reactions

Gamma-rays are electromagnetic radiation of nuclear origin, of very short wavelength, emitted by the nuclei of certain atoms in the course of their radioactive decay. Gamma rays are not composed of particles but consist of high energy photons; they have the speed of light, have no electric charge or rest mass, but do have a very slight mass due to their motion and velocity. The wavelength of a gamma ray is a characteristic of the atom emitting it. Penetration power is inversely proportional to the density of the substance penetrated. The absorption of gamma ray photons by matter occurs as follows: (1) low energy gamma photons are absorbed by the photoelectric effect in which a small part of their energy is spent in dislodging an orbital electron, and the remainder is imparted to the dislodged electron as kinetic energy; (2) high energy gamma photons undergo Compton scattering in which a gamma photon makes an elastic collision with an outer orbital electron, dislodging it and transferring part of its kinetic energy to the electron; (3) pair production in which a gamma photon with energies in excess of 1.02 Mev pass near the nucleus or orbital electron of an atom and is annihilated in the strong electric field with the formation of an electron-positron pair. The loss of an electron, as described above, leaves the atom in an ionized or excited state so it can migrate in applied electric fields or take part in chemical reactions.

1.4 Combined Neutron and Gamma Photon Environment

The nuclear environment created by the fission process which passes through the water moderator consists primarily of neutrons and gamma photons but once these forms of energy interact with matter as described in 1.2 and 1.3 the nuclear environment is altered with the production of secondary forms of radiation. The nuclear radiation environment to which the test samples were exposed consisted of gamma photons, ionized atoms, electrons, positrons, protons, alpha particles, beta particles, and x-rays. The combined effects of all these forms of radiation on matter differ for certain types of compounds and include:

(a) Metals - among the changes which are generally produced in metals by radiation are increases in electrical resistance, in thermal resistance, in hardness and tensile strength, and moderate changes in dimensional stability. Neutrons cause the majority of the damages in metals.

(b) Semi-conductor devices are among the most susceptible electronic components to radiation damage. Their electrical parameters are related to the atomic crystalline structure, which is susceptible to dislocations by energetic particles and energy. Contrary to the behavior of most metals, semi-conductors are affected not only by neutrons but also by gamma photons. Both transient and permanent effects are produced in the semi-conductor.

(c) Organic compounds are the most susceptible class of materials to nuclear radiation induced changes. The predominant damage mechanism is by ionization and results in permanent changes in physical, electrical, and chemical properties.

APPENDIX XI

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